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Change of Structure in Iron and Steel.

WM. CAMPBELL. Ph.D., Sc.D., Columbia University.

In a former paper, which I had the honor to present to the Institute, in February, 1904, the changes which take place in the solid state were illustrated by the alloys of copper and aluminum, copper and tin, and iron and carbon. In the present paper the changes which take place in the iron-carbon series will be further considered in the light of more recent work and an attempt will be made to clear up one or two points wherein practice and theory do not always agree.

The Constitution of the Iron-Carbon Series.

The constitution and structure of iron and steel have been thoroughly worked out and with this subject will always be associated the names of Sir Wm. Roberts-Austen and J. E. Stead, in England; of F. Osmond and H. Le Chatelier, in France; of A. Mar-

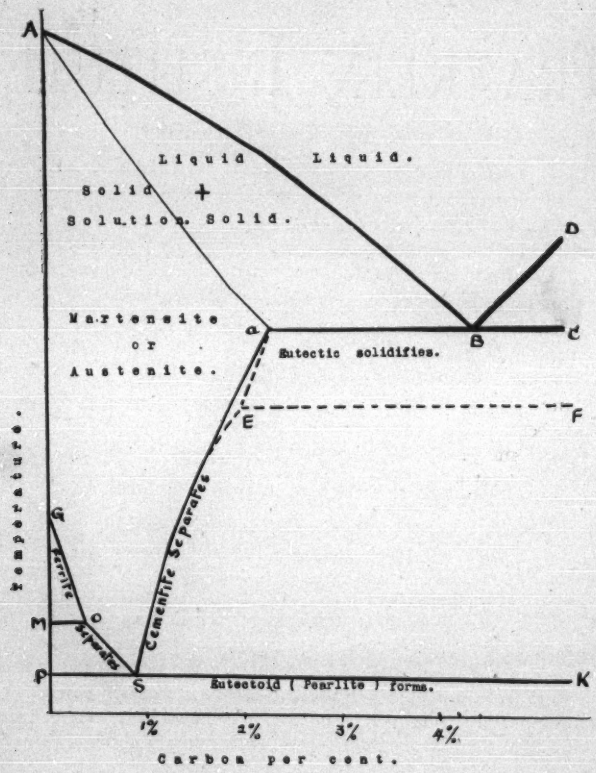
A
Liquid
Liquid.
Solid
+
Solution. Solid.
D
Martensite
or
Austenite.
a
B
C
Eutectic solidifies.
E
F
Temperature.
G
Ferrite
separates
Cementite Separates
M
O
P
S
Eutectoid (Pearlite) forms.
K
1%
2%
3%
4%
Carbon per cent.

Fig. 25

tens and E. Heyn, in Germany; and H. M. Howe and A. Sauveur, in this country, out of a long list of workers.

In the solid state we recognize three forms of pure iron α, β, γ and whose transformation points are 760° and 900° c. The solubility of carbon in γ iron reaches a maximum of about 2% whilst in α iron it is nil.

To Roberts-Austen* we owe the first temperature-composition curve for the series, which consisted of the lines A B D, a B C, G O S E, M O and P S K. In his lectures he taught that the alloys of iron and carbon consisted of two constituents in freezing, namely, graphite and a solid containing up to 2% of carbon in solution. That at a lower temperature this solid containing carbon in solution re-arranged itself into two constituents, ferrite or pure iron and cementite or iron carbide, just as the series ice-salt changes from the liquid to the solid state on fall of temperature. Similar curves were obtained by Osmond and by Le Chatelier independently.

In 1899 was issued the Fifth Report to the Alloys Research Committee of the Institution of Mechanical Engineers. Therein is described the method of obtaining differential cooling curves. By this method, in cooling electro-iron from a white heat, evolutions of heat were found at:—

A. at 1132° C. the Ball point.
B. at 895° C. the Ar3 point of Osmond.
C. at 766° C. the Ar2 point of Osmond.

The carbon point Ar1 denoting the formation of pearlite, of course, does not exist in carbonless iron. Three lower points, however, were found, one between 550° and 600°, another between 450° and 500° and a small evolution of heat at 261° C. These lower points are due to the occlusion of hydrogen.

The curve for the iron-carbon series was corrected and brought up to date. The point A (Fig. 25) was placed just below 1600° C., a at 1.2% carbon and 1120° C., B at 4.3% carbon, G at 890° C., M at 770° C., S at 690° C. between 0.8 and 0.9% carbon. The point E at 1.8% carbon and 1000° C. formed the summit for the curve denoting the separation of cementite, which falls with increase in total carbon, till at about 4.25% carbon it meets the line S K, and ends. Above 4.25% carbon ferrite sep-

*Fourth Report to Alloys Research Committee, Pl. ii.

arates. The two lines denoting the separation of cementite and ferrite above 2% carbon were hypothetical. Just below the line a B C, a parallel line was drawn at about 1060° C. on the suggestion of H. Le Chantelier to denote the possible solidification of cementite eutectic in White Iron.

Starting with Roberts-Austen's data, Roozeboom for physical-chemical reasons added to the curve so that certain principles of solution were brought out thereby. His modification consisted essentially of adding the lines A a, a E and E F. The beginning of freezing is represented by A B D the liquidus, whilst A a B C the solidus denotes the end of freezing and below these limits the alloys are solid. When a liquid alloy cooled down to the temperature A B dendrites separated out and contained a maximum of 2 per cent. carbon in solid solution. These mixed crystals were called Martensite.* In alloys containing more than 2 per cent. carbon a groundmass, the Martensite-graphite eutectic, makes its appearance and is denoted by the horizontal line a B C. The branch B D denotes the separation of free graphite. Thus we find that from 0 to 2 per cent. carbon the alloys solidify as mixed crystals (solid solutions); from 2 to 4.3 per cent. or a to B the alloys solidify as dendrites of the solid solution (2 per cent. carbon) set in an increasing groundmass or eutectic of graphite and the solid solution; whilst above B or 4.3 per cent. carbon we have free graphite and the eutectic. Beneath the line a B C at 1130° c., therefore, we are dealing with a solid conglomerate of two phases, graphite and Martensite, with 2 per cent. of carbon in solution. The line a E indicates that the amount of carbon in the solid solution falls with the temperature and we have a further separation of graphite till at about 1000° c. and 1.8% c., the line at E meets the cementite line S E of Roberts-Austen. This means that in the normal state of equilibrium we have an abrupt transformation thus:—

Martensite (1.8 per cent. c.)+Graphite=Cementite (Fe_3C).

The temperature 1000° is therefore a transition point, in other words, at this temperature only can we have three phases in equilibrium, therefore in all alloys the transformation of Martensite and graphite into cementite must occur at this temperature which is denoted by the horizontal line E F. As the tem-

*See Appendix.

perature falls below 1000° c. the solubility of carbon in solid solution Martensite decreases and we have the separation of cementite along the curve E S. This continues until we reach the line P S K at 690° when the residual Martensite, with 0.85 per cent. carbon in solution changes over into a conglomerate of ferrite and cementite, which we call pearlite. The formation of this eutectoid pearlite causes recalescence. To sum up, according to the work of Rooseboom, in slowly cooled iron or steel in equilibrium we should only find ferrite and cementite.

The publication of Rooseboom's application of the phase-rule to the iron-carbon series* raised quite a storm of criticism, mostly practice versus theory. It was argued that in most cast-irons we find ferrite, cementite and graphite; that the data on which the work was founded were wrong; that the phase-rule was not applicable outside strictly chemical lines and so forth. In the first place, most cast-irons are not pure alloys of carbon and iron. In the second, they are very seldom in equilibrium. The reaction between Martensite and graphite to form cementite would naturally be extremely slow and hence in ordinarily cooled cast-iron we should expect to find graphite by lag. It was pointed out that the reverse, cementite changing to graphite and Martensite, occurred quite readily in the manufacture of malleable castings. On the other hand rapid cooling tends to produce much cementite, while slow cooling yields much graphite.

In regard to the accuracy of the data, Carpenter and Keeling† ran a series of cooling curves for 38 alloys of carbon and iron as pure as possible and their results confirm the accuracy of Rooseboom's diagram, allowing for the differences in their determinations. For example, their freezing point for pure iron begins at 1505° c. For the eutectic alloy with 4.3 per cent. carbon at 1139° c. The line a B C rises slightly from about 1110° c. at 2 per cent. carbon to 1122° c. at 2.25 per cent. carbon, to 1139° c. at 2.75 per cent. carbon. The line P S K rises slightly also from about 690° c. with 0.12 per cent. carbon to 700° c. with 0.9 per cent. carbon, to about 710° c. with 2 per cent. carbon. G occurs about 900° c. and M about 760° c. Hence we may judge that the data were accurate.

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*Journal Iron and Steel Inst., 1900, ii, p. 311.

† National Physical Laboratory. Collected researches, i, pp. 227-244.

PLATE I. Figs. 1-6

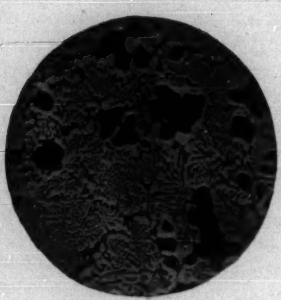


Fig. 1

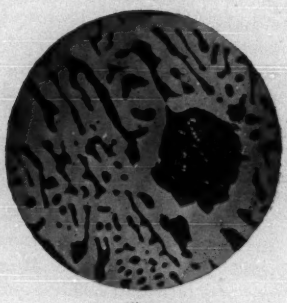


Fig. 2

Fig. 3

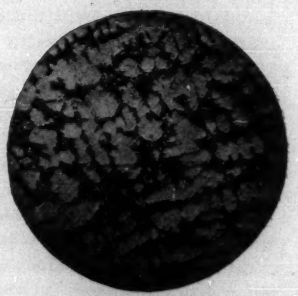


Fig. 4

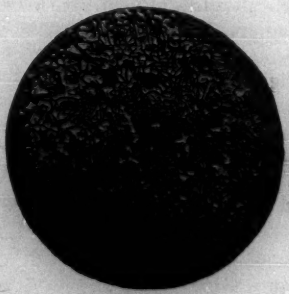


Fig. 5

Fig. 6

Whilst Rooseboom's interpretation might readily be accepted for gray cast-irons, when we consider the structure of white cast-irons (shown in figs. 1, 2 and 3) we see that the groundmass or eutectic consists of primary cementite and the solid solution Martensite which afterwards transformed into pearlite. Were graphite a primary product and cementite a secondary one, slow cooling ought to promote the occurrence of the latter, rapid cooling yielding the former. It is a well-known fact that slow cooling promotes the formation of graphite and rapid cooling or chilling gives us cementite. The presence of silicon usually emphasizes this effect.

It seems to make the subject clearer, if we consider the two classes of cast-iron separately.

White Cast Irons. Alloys of Martensite and cementite. The line A B denotes the freezing of crystals or dendrites of Martensite holding a maximum of 2 per cent. carbon in solid solution as cementite; the line B D denotes the freezing of crystals or plates of cementite, whilst the line a B c shows the solidification of the groundmass or eutectic of Martensite and cementite. Thus up to 2 per cent. carbon the alloys form a series of solid solutions or mixed crystals, Martensite. Between a and B or from 2 to about 4.3 per cent. they consist of dendrites of Martensite surrounded by an increasing matrix of Martensite and cementite, the eutectic. Above B or 4.3 per cent. they consist of increasing amounts of cementite plates set in the same eutectic or groundmass. Fig. 1 magnified 60. is a section of washed metal containing 3.75 per cent. carbon. Si = 0.03 : P = 0.012 : S = 0.020. It consists of a few dark etching grains of Martensite set in a groundmass which is a mixture of dark-etching Martensite and bright cementite and is the eutectic. Fig. 2 shows a portion of the same under 260 diameters. The alloys occurring on the right of B are illustrated in fig. 3, which is a section of speigeleisen very slowly cooled, magnified 50. It consists of plates of cementite (here a carbide of iron and manganese) set in the eutectic of Martensite and cementite.

With fall of temperature below a B c, say 1125° c. the Martensite becomes supersaturated with cementite, being no longer able to hold 2 per cent. of carbon in solution. The cementite therefore separates out along the line a S which denotes the composition of the Martensite with fall of temperature till at 700° c.

or the temperature P S K, the residue contains 0.85 per cent C. and splits up into a mixture of ferrite and cementite or the eutectoid pearlite. Hence the final products will be cementite and pearlite, which are the constituents of figs. 1, 2 and 3, the pearlite appearing black, the cementite white. We have, therefore, three generations of cementite (a) the constituent of the eutectic which solidified at 1135° c., (b) the excess which separated on the line a S, (c) the constituent of the eutectoid pearlite.

Gray Cast-Irons. Alloys of Martensite and graphite. The line A B denotes the beginning of the freezing of dendrites of Martensite: the line B D the separation of flakes of graphite, whilst a B c shows the solidification of the groundmass or eutectic of Martensite and graphite at 1135°. Thus we have replaced the cementite of our white irons by graphite. There is one other great difference, however. The Martensite which separates out does not have a constant amount of carbon in solid solution. In other words the point a can vary from 2 to 0 per cent. carbon. As the temperature falls the Martensite (0—2 per cent. C.) rearranges itself into ferrite and pearlite or cementite and pearlite or pearlite alone according as the percentage of dissolved carbon was less than, greater than or equal to 0.85 per cent., following the curves G O S and S a. If we follow the Rooseboom diagram for gray-irons with say 2 per cent. combined carbon at a then we have the reaction at E to form cementite, which, of course, is incomplete. When a moves to the left, as it does with increase in silicon and from other causes, the phase-rule still requires that there should be the reaction:—Martensite (up to 2 per cent. carbon) + graphite = cementite—in order that we may only have two phases. In general this would tend to take place wherever the curve denoting the solubility of graphite in Martensite cuts the line denoting the separation of cementite.

Many observers find that cementite forms in some gray iron right from the solidification point 1135° c., which would mean the raising of E F till it coincided with a B c.

The structure of the series is well shown in Fig. 4 magnified 50. dia's. a piece of cast-iron with 2.9% C: 1.44% Si: 0.23% Mn very slightly etched. Light dendrites of Martensite a seen set in a groundmass which is the eutectic of Martensite and graphite. Fig. 5 × 35 diameters shows the eutectic alloy of Martensite and

graphite, a structure of common occurrence in gray pig-iron. Fig. 6 shows the same under the higher magnification of 120 dias. and the coarsest part of the specimen. As before the Martensite on cooling down rearranged itself by separating out ferrite or cementite and recalesced at 700° c. forming pearlite.

All irons between white and gray consist of grains of gray surrounded by a network of white, the gray apparently freezing a little ahead of the white.

The explanation that the cause of the difference between white and gray iron is silicon, does not always hold good. Carpenter and Keeling's alloys show with about 0.16% Si, up to 3.0% carbon, it was all combined, but an alloy with 0.06% Si yielded 2.14% graphite out of 3.87% total carbon. In Wüst's works* up to about 3 per cent. carbon there was only a little graphite, whilst one alloy with 0.009% Si gave 2.33% graphite with 3.76% total carbon and another with .011% Si gave 3.31% graphite out of a total carbon of 4.82%. In these exceptional cases silicon can hardly be the cause of the graphite.

Stansfield in a paper on the Present Position of the Solution Theory of Carburized Iron† comes to the conclusion that graphite does not combine with iron on slow cooling to 1050° C. and that the 2% of carbon which the iron at first holds in solid solution is rejected as graphite and not as cementite, if the metal is cooled sufficiently slowly. Instead of the line a E denoting the further separation of graphite and cutting the cementite line S E at E, a line a S′ is drawn to the left of and parallel to E S, so as to cut G O. This new line denotes the solubility of graphite in Martensite, which is therefore much less than that of cementite in Martensite. That graphite is not formed in steel he concludes, is due partly to the absence of nuclei of graphite on which further deposits might take place, partly to the length of time required for the separation of graphite, and partly to the mechanical pressure which must oppose the formation of bulky graphite in steel. The Phase Rule demands that in equilibrium there be but two constituents present. Graphite being the more stable, these two constituents must be ferrite and graphite.

*Metallurgie, ii, p. 1.

† Journal of the Iron and Steel Institute, 1900, II 317

THE STRUCTURE AND TREATMENT OF STEEL.

Wrought Iron and Steel. When we pass from wrought iron, through mild steel, low carbon, medium and high carbon steels to those with a maximum of 2 per cent. of carbon, we embrace all that part of the curve which lies on the left of a or 2% carbon. Up to 0.85% carbon we have ferrite or pure iron and the eutectoid pearlite in increasing amounts. From 0.85 to 2% carbon we have cementite Fe_3C and the eutectoid pearlite in decreasing amounts. Fig. 7 × 90 dias is a longitudinal section of a piece of wrought iron bar which consists of ferrite and long threads of slag. The ferrite occurs in the form of polygonal grains which can be seen in fig. 8 × 260, a piece of wrought iron pipe. The slag is seen to be composite with lighter grains set in a darker groundmass. When wrought iron is strained beyond its elastic limit slip-lines are set up as in a pure metal. Fig. 9 × 80 shows several systems of parallel slip-lines in a piece of wrought iron with an extremely coarse grain. The section is perpendicular to the rolling and the round globules are cross sections of slag. Where the strain is extreme, the slag breaks up as is shown in fig. 7, which is a vertical section through a test-piece at the point of rupture. The slag has broken up into fragments between which the plastic ferrite has flowed in.

The difference between wrought iron and steel of very low carbon is mainly the absence of slag. Fig. 10 × 110 dias. shows some steel with 0.035% carbon slowly cooled from 1100° c.: it is composed of irregular grains of ferrite, with a few black dots of pearlite containing 0.85% carbon. Its physical properties are:*

	Elastic Load	Max. Load	Elong. 8″	Red. of area
As rolled	23,000	44,000	30%	68%
Annealed at 700° 3 hours . . .	26,000	41,500	33%	67%
Heated to 820°, quenched in water	34,000	56,000	9%	77%

Campbell gives an elastic limit of 27,000 lbs. per sq. in. and a maximum load of 46,000 for open-hearth steel running c. .04 Mn .04. Annealing such material for a long time at temperatures

*See Mathews J. I. and S. Inst., 1902, I.

below 750° c. causes a rapid growth of grain and the crystals become quite coarse. Reheating to just about 900° c., i.e., G in fig. A, causes refining.

An increase in carbon causes an increase in the pearlite, with an increase in strength and a decrease in ductility. Fig. 11 × 250 shows a steel with 0.10% carbon. It consists of small grains of ferrite with a few black patches which are pearlite with 0.85% carbon. Heating for a long time just below 700° causes such pearlite to segregate and split up. The ferrite is absorbed by the surrounding grains, whilst the cementite is left as islands in the midst of the ferrite. A long heating below about 750° c. also causes a coarsening of grain, whilst heating to just below 900° (G O) causes refining. Above this, the higher the temperature the coarser the grain till we reach A a where burning occurs. The coarsening of grain is very rapid above 1300° c.

A rivet steel* with C 0.10 Mn 0.40 P .011 S .01 has:—

	Tensile S.	Elastic load	Elong. 8″	Red. of area
As rolled	55,000	37,500	33%	62%
Annealed	50,500	31,000	35%	68%

Fig. 12×260 dias. show some steel containing 0.16% carbon which ought to give an elastic limit of about 45—50,000 lbs. per sq. in., and 65,000 maximum load with 21% elongation in 8 inches and 60% reduction of area. It is not cast steel, however, but is a photo from an area in some so-called puddled iron. The tensile tests showed up abnormally and the microscope revealed the presence of numerous areas of steel. The material is "piled" iron, made by reheating a mixture of scrap steel and wrought iron to a welding heat and rolling them out. The dark rolling lines containing slag are seen in fig. 12.

The following figures are taken from Campbell*:—

Wrought iron plate.
Elastic limit 31,000 lbs., Tensile S. 50,000.
Elongation in 8″ 15—17%. Red. of area, 22—24%.

*Manuf. and Props. of Iron and Steel, 1907, p. 248, p. 91.

PLATE II. Figs. 7-12

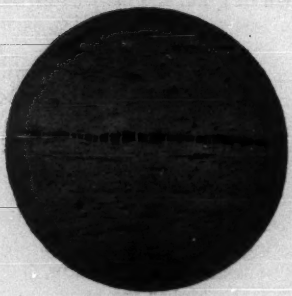


Fig 7

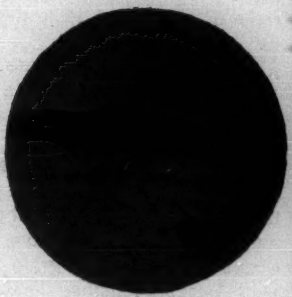


Fig. 8

Fig. 9

Fig. 10

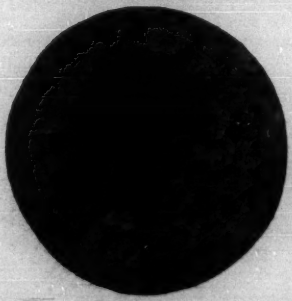


Fig. 11

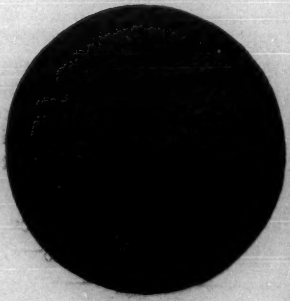


Fig. 12

Chain. variations in specimens.

Tensile strength	47,500	to	70,000
Elongation 8 inch	6½%	to	32½%
Red. of area	7½%	to	60%
Slag	1/10	to	2¼%
Carbon	.015	to	.5
Phosphorus	.065	to	.317
Silicon	.028	to	.321

Such figures show that we may expect any results from wrought iron manufactured from steel scrap.

At about .45% carbon the amount of ferrite equals that of the pearlite in slowly cooled material. When, however, the steel has been cooled comparatively rapidly, as for instance in air, there is much more pearlite than ferrite. In other words, the pearlite contains less than .85% c. or is still holding ferrite in solution. Fig. 13 × 260 dias. shows some steel containing 0.53% carbon annealed.

In a former paper* the heat treatment of a steel running C = .0.5% Mn 1.0% was discussed.

	Elastic Limit	Max. Load	Elong. 8″	Red. area
As rolled	70,500	113,500	14	46½
Heated to 720°	63,700	102,300	17½	54½

The effect of reheating to the critical point is to reduce the strength some 10%, but this also increases the ductility. Overheating occurs about 1250° c., while refining occurs at about 720° c., midway between Ac_1 and $Ac_{2\text{-}3}$.

As we approach 0.85% c. the ferrite steadily diminishes. Fig. 14 × 260 dias. shows a steel containing C = .72 Mn .34 cooled slowly from 1050° c. The patches of ferrite are now but few and isolated. A similar steel with C = .72 Mn .22 gave

	Maximum Load	Elong. 2″	Red. of area
As rolled	118,000	16%	28
Heated to 720°	88,000	23%	48
Heated to 800°	92,000	18%	32

*Change of Structure. J. Frank. Inst., Sept., 1904.

At 0.85% carbon the steel consists of pearlite only, has one critical point S at 700° c. When we increase the carbon above this point, the excess separates out as cementite on the line a S, thus reducing the residual Martensite to 0.85% c. which recalesces at 700° c. with the production of pearlite as before. Fig. 15 × 260 dias. shows a piece of steel with 1.54% carbon 0.3% Mn. slowly cooled from 1050° c. Bright, hard veins of cementite surround the pearlite grains, whose pearly appearance shows up well, due to the slow cooling.

The effect of heat treatment on tool steels is of great importance. The following tables and curves give a summary of the results obtained on a series of 6 crucible steels 5-16 in. square running an average of 0.2% Mn. 0.01% P. 0.01% S and .2% Si. after heating to temperatures varying from 650 to 1200° c. and slowly cooling.

On examining the curves we find that the maximum loads show a great falling off till we reach the 760° c. heat, beyond which they remain fairly constant until at 1070° c. heat where extreme overheating comes in. Steel 5 shows a curious regain of strength from the 760° c. to the 855° c. heat beyond which it is constant. The elongations show a maximum for steels 6 to 3 with heat 760° c. and for steels 2 and 1 at the 800° c. heat. The reductions of area show maximum at the 715° c. heat for steels 6 and 5, at the 760° c. heat for steels 4, 3 and 2, at the 800° c. heat for bar 1. The fractures of the test-pieces showed that for the two lower carbon steels 0.7% and 1.04% overheating occurred at so low a temperature as 800° c., but with the others, higher in carbon, the temperature was above 1000° c. before extreme overheating occurred. The steel with 1.61 per cent. carbon remains the strongest to the 800° c. heat, but at the 855° heat the bar with 1.04 per cent. carbon has the greatest strength, which it maintains. Note how the 800° heat has equalized the strengths.

On examining the microstructure we find that heating to temperatures below the critical point causes a breaking down of the veins of cementite which tend to assume a globular form (e. g., change from fig. 15 to 16) and a change in the character of the pearlite. The size of grain of the pearlite does not change until the critical point has been passed. Above the critical point the higher the temperature the coarser the grain of the pearlite and the more the segregation of the cementite into globules until at

PLATE III. Figs. 13-18

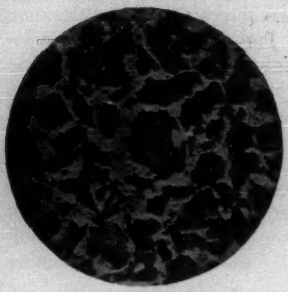


Fig. 13

Fig. 14

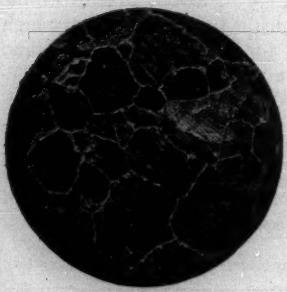


Fig. 15

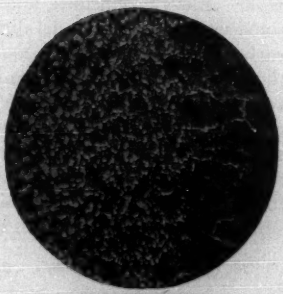


Fig. 16

Fig. 17

Fig. 18

above 1000° c. we find the cementite breaking down into ferrite and graphite. Fig. 16 × 260 dias. shows the steel containing 2.04% carbon heated to 950° c. The cementite has drawn together in globules, whilst on the right of the figure decarbonization of the outside of the specimen is shown by the pearlite alone. Fig. 17 × 260 dias. shows the steel containing 1.61% carbon after heating to 1070° c. We have a groundmass of coarse pearlite with a few thin veins of cementite. Most of the cementite, however, has decomposed, forming the black globules of graphite. On heating to a temperature of 1200, however, all of the cementite is taken into solution and separates out on cooling down again. Fig. 18 × 60 dias. shows the steel containing 1.72% carbon heated to 1200° c. and slowly cooled. We have extremely coarse grains of dark etching pearlite surrounded by white veins of cementite and cut by numerous needles of the same set in several parallel directions. In the case of very high carbon steels heats above 1200° c. for any time cause a melting, the carbon segregates and we have white cast-iron produced between the grains. Fig. 19 × 260 shows a steel with 2.04% carbon heated to just above 1200° c. and slowly cooled. It consists of grains of overheated steel like fig. 18 set in a groundmass of white cast-iron. Thus we judge that the normal eutectic of iron and carbon is the cementite one and that in the absence of silicon graphite is the product of decomposition of cementite.

Table 1. Bars as Received.

Bar No.	Elastic Limit Lbs. per	Maximum Load square inch	Reduction of Area %	Elongation in 2″ %	Carbon %
1ª	101,800	144,600	3.53	4 5	2.04
2ª	91,000	146,500	6.5	6.0	1.94
3ª	98,700	152,800	5 25	6.5	1.72
4ª	105,200	162,200	8.17	7.0	1.61
5ª	75,800	140,600	22.7	13.5	1.04
6ª	65,300	117,400	27.3	17.0	0.70

Table 2. Bars as Received.

Bar No.	Elastic Limit Lbs. per	Maximum Load square inch	Reduction of Area %	Elongation in 2″ %	Carbon %
1^x	104,200	144,000	3.04	4.0	2.04
2^x	91,500	146,300	6.0	6.5	1.94
3^x	97,500	154,000	8.68	8.0	1.72
4^x	105,200	153,200	9.14	6.0	1.61
5^x	75,800	141,600	21.8	12 0	1.04
6^x	64 200	116,600	27.0	17.0	0 70

Tables 3, 4 and 5

	Bar No.	Elastic Limit	Maximum Load	Reduction of area %	Elongation in 2″ %	Carbon %
Bars heated to 650° C.	1^3	84,600	115,400	6.52	6.0	2.04
	2^3	72,600	115,200	8.92	8.0	1 94
	3^3	78,300	126,000	7.33	8.0	1.72
	4^3	85,300	128,100	8.28	——	1.61
	5^3	57,700	105,400	36.2	18.0	1.04
	6^3	53,250	95,200	33 9	23.0	0 70
Bars heated to 715° C.	1^1	83,900	114,500	6.6	7.0	2.04
	2^1	68,660	104,100	11.97	9.5	1.94
	3^1	75,700	114,100	18.78	11.5	1.72
	4^1	81,300	117,000	21.5	14.5	1.61
	5^1	55,200	97,800	41.5	22.0	1.04
	6^1	49,700	88,700	45.2	27.5	0.70
Bars heated to 760° C.	1^6	57,700	98,800	16.16	11.5	2.04
	2^6	50,500	95,000	18.8	15.0	1.94
	3^6	50,500	100,300	20.5	16.5	1.72
	4^6	52,300	98,650	34.0	20.0	1.61
	5^6	44,850	86,800	36.6	26 5	1.04
	6^6	40,200	85,600	38 75	27.0	0.70

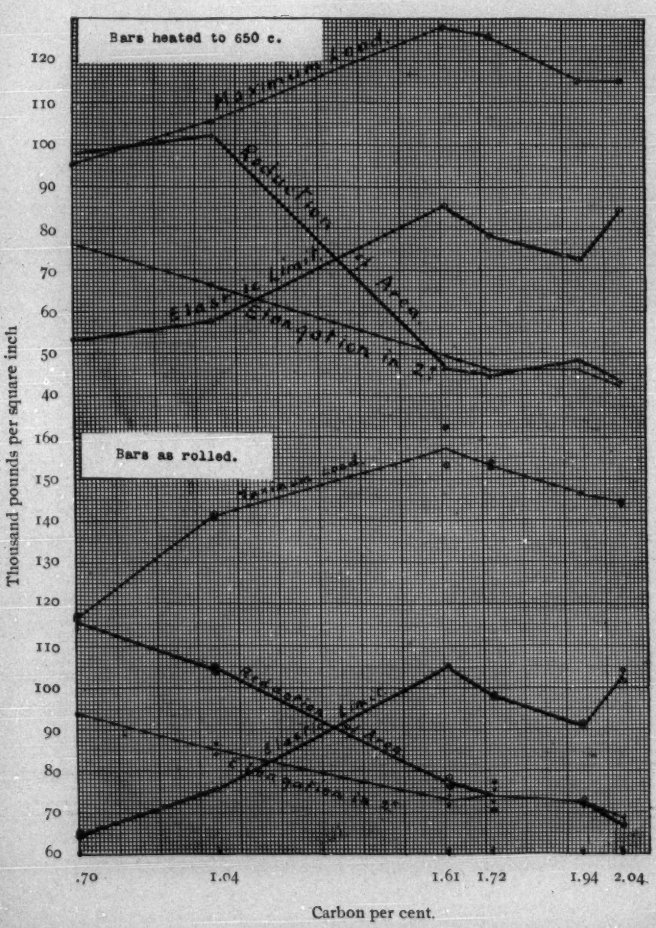
Tables 6, 7 and 8

	Bar No.	Elastic Limit	Maximum Load	Reduction of area %	Elongation in 2″ %	Carbon %
Bars heated to 800° c.	1^2	57,800	95,650	19.6	12.5	2·04
	2^2	51,000	92,000	15.0	17.0	1.94
	3^2	48,750	98,000	10.26	10.0	1.72
	4^2	53,350	97,700	19 1	18.5	1.61
	5^2	46,600	96,600	21.0	19 0	1.04
	6^2	42,150	94,300	20.9	19.0	0.70
Bars heated to 855° c.	1^4	55,500	93,800	13.2	12.0	2.04
	2^4	49,450	89,200	12.15	12.5	1.94
	3^4	47,900	94,000	12.0	13.5	1.72
	4^4	51,350	95,000	14.24	15.0	1.61
	5^4	47,200	111,800	11.3	13.0	1.04
	6^4	42,100	91,350	20.75	18.5	0.70
Bars heated to 905° c.	1^0	55,350	95,250	12.56	11.5	2.04
	2^0	49,800	93,350	9 48	7 0	1.94
	3^0	48,600	94.350	9 65	11.0	1.72
	4^0	51,350	97,350	9.4	11.5	1.61
	5^0	50,600	115,900	8 78	13 0	1.04
	6^0	41,400	90,300	21 8	18 0	0.70

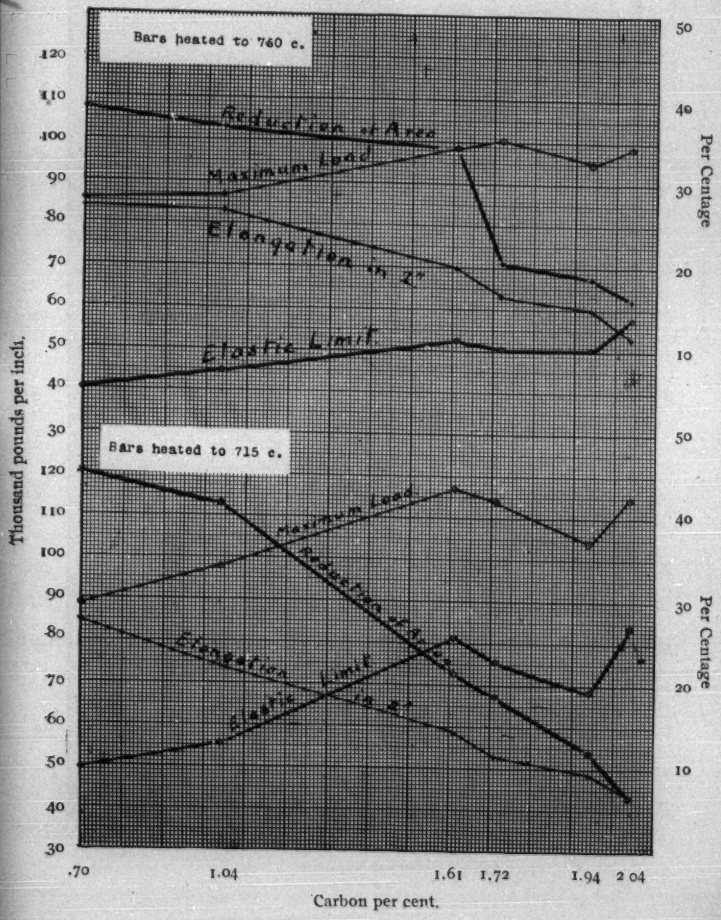
Tables 9, 10 and 11

	Bar No.	Elastic Limit	Maximum Load	Reduction of area %	Elongation in 2″ %	Carbon %
Bars heated to 950° C.	1^5	49,350	95,200	5.8	6.0	2.04
	2^5	41,750	91,800	12.0	9.5	1.94
	3^5	45,200	95,000	6.33	7.5	1.72
	4^5	48,500	96,350	6.78	7.5	1.61
	5^5	46,800	111,500	10.92	10.5	1.04
	6^5	39,700	90,500	20.5	16.5	0.70
Bars heated to 1070° C.	1^z	49,600	99,000	2.72	4.5	2.04
	2^z	47,000	97,000	7.6	8.5	1.94
	3^z	43,100	92,350	4.31	6.0	1.72
	4^z	51,400	94,400	2.57	3.5	1.61
	5^z	56,500	106,100	10.58	11.0	1.04
	5^z	57,350	89,500	17.94	18.0	0.70
Bars heated to 1200° C.	1^s	56,000	57,400	0.4	1.0	2.04
	2^s	——	61,350	1.41	2.0	1.94
	3^s	50,600	65,300	1.02	2.0	1.72
	4^s	——	69,800	1.86	3.0	1.61
	5^s	89,600	112,600	10.7	11.5	1.04
	6^s	58,500	90 000	16.84	16.0	0.70

Curves 1 and 2



Curves 3 and 4



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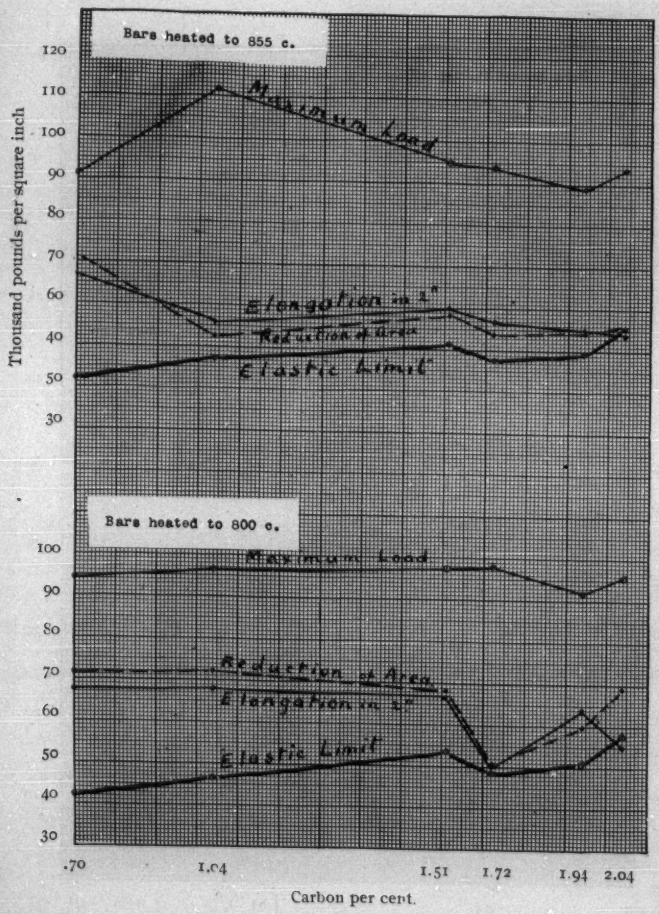
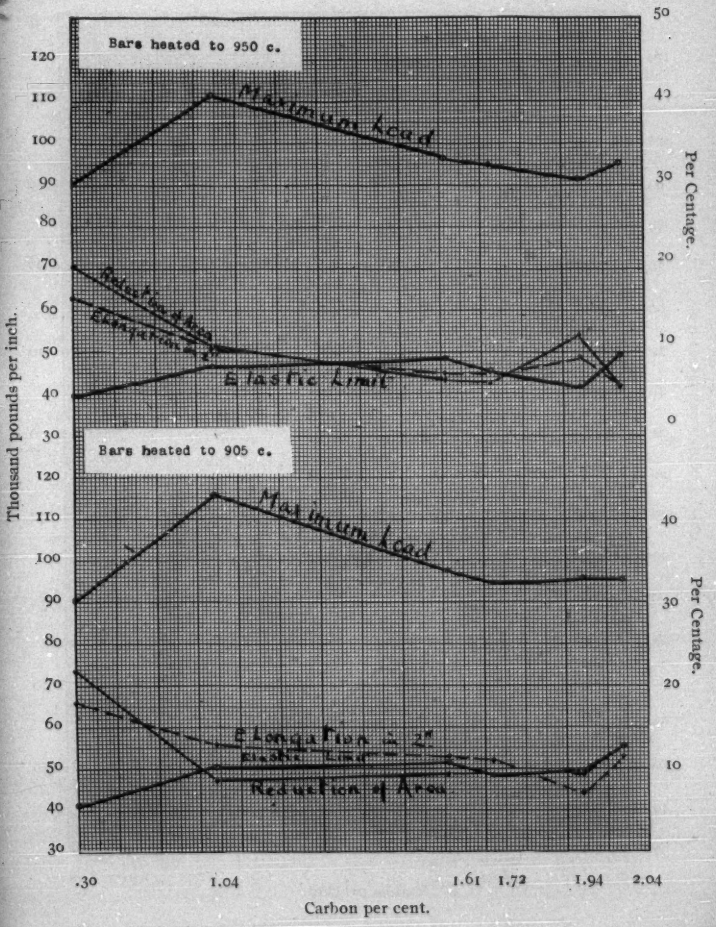
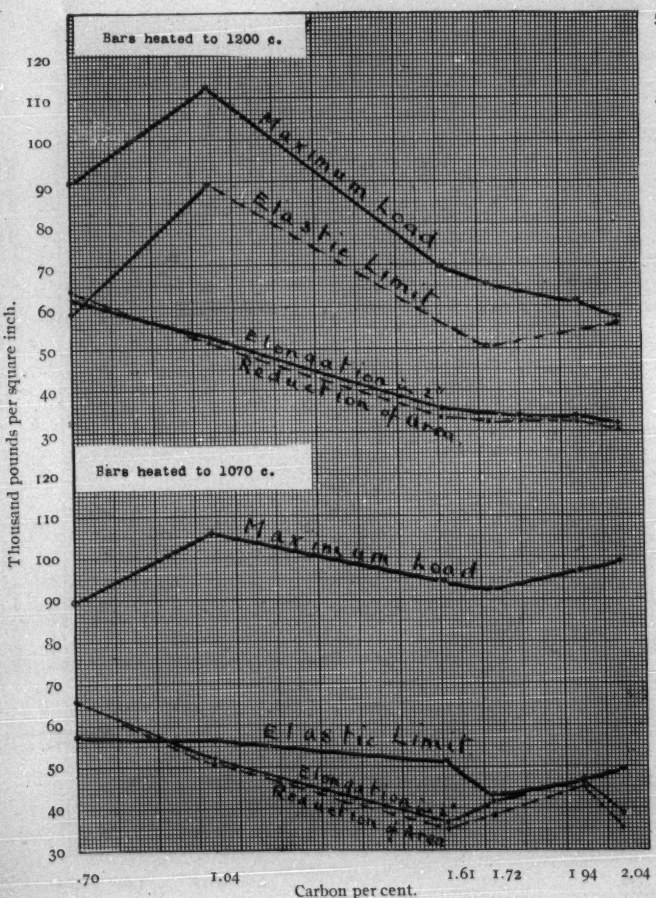


Curves 7 and 8



Curves 9 and 10



Heat Treatment of Cast-Iron.

In the manufacture of malleable castings from white cast-iron on passing 700° c. the pearlite changes over into Martensite: at a little above 1000° c. the cementite breaks down into ferrite and graphite. Is silicon essential to the process? Most people think so. Tiemann* made some silicon free cast-iron with total carbon 4.5, graphite .255. This material was heated to all temperatures up to the melting point without causing the cementite to decompose. On the other hand, Wüst, with a white iron of 3.8% carbon and not more than 0.008% Si on heating for 50 hrs. at 980° C. in a vacuum and slowly cooling produced a product consisting entirely of pearlite ferrite and temper carbon, the whole of the cementite having decomposed.

An experiment was performed with some pieces of washed metal (C = 3.75 Si 0.03) which were heated to about 1050° c. in an oxidizing atmosphere. Fig. 20 shows a section near the surface of one of the pieces. In the center we have the original white cast-iron showing no trace of graphite, whilst around it lies an area of cementite and pearlite running about 1.5% carbon, due to decarbonization. No sign of any graphite was seen. One specimen, however, did show graphite, seen in fig. 21. On the right lies the original white cast-iron, whilst on the left we have material corresponding to about 1.5% carbon steel, well mixed with graphite flakes. Thus in one specimen we found the decomposition of cementite into graphite had occurred, whilst in all the others it failed to appear. This shows that the reaction is not constant under the conditions used, and that sometimes graphite appears, in others the cementite remains undecomposed.

Cementite in solution in the Martensite is certainly stable at these temperatures as shown by fig. 18. The process of making Blister Steel also shows this. Wrought iron is heated to a bright red or white heat in contact with carbon. The iron is in the γ range and Martensite is formed by diffusion. Fig. 22 × 60 dias. shows some half cemented steel which is composed of bright ferrite and darker, coarse pearlite. Fig. 23 × 260 shows the same: the pearlite is seen to be extremely coarsely laminated with a band or border of cementite due to segregation in slow cooling. Fig. 24 × 260 shows some fully cemented bar. The black

*Metallographist, iv 303.

PLATE IV. Figs. 19-24.

Fig. 19

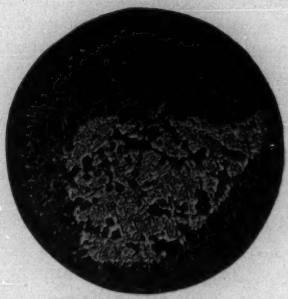


Fig. 20

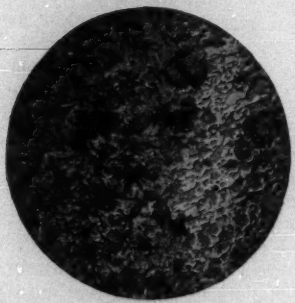


Fig 21

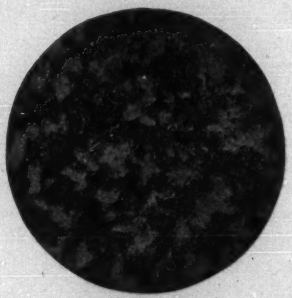


Fig. 22

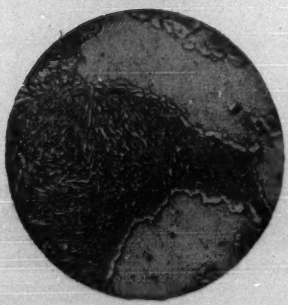


Fig. 23

Fig. 24

streaks are the original slag of the wrought iron. Slow cooling has produced a coarse pearlite in which are set thick veins and patches of cementite. Thus we can produce a cement steel up to 2 per cent.+of carbon without forming graphite, but reheating the same would cause the formation of graphite due to the breaking down of cementite around 1050° C.

SUMMARY.

From our present knowledge we must judge the cementite-Martensite series to be the unstable one. Absence of silicon and rapid cooling tend to cause white cast-iron. When high carbon steels are heated to their melting point and slowly cooled, white cast-iron is formed. Pure cast-irons with a comparatively small amount (2—3%) of carbon tend to be white.

Gray cast-irons are the Martensite-graphite series which occur with much silicon and slow-cooling. The presence of much carbon (3%+) tends to produce a gray iron.

Graphite is formed due to the decomposition of cementite by reheating to temperatures around 1000° C. In steel a higher temperature (to melting) causes the solution of the cementite or formation of white cast-iron. In malleable castings the action is similar, cementite breaking down into ferrite and graphite. Too high a heat retards and even prevents this reaction.

Most cast-irons are a mixture of white and gray or cementite, Martensite and graphite, the gray forming a mesh in a network of white cast-iron which forms at a slightly lower temperature. This structure is probably due to the presence of silicon, manganese, phosphorus and sulphur in varying amounts.

The simultaneous occurrence of cementite and graphite in certain specimens of siliconless irons can not be explained satisfactorily except by assuming that we are dealing with two systems:—

(a) Ferrite and Graphite,
(b) Ferrite and Cementite,

which Benedicks calls the stable and the meta-stable systems respectively. This does away with the necessity of assuming a reaction between graphite and Martensite to form cementite in the region of 1000° C. which Rooseboom himself no longer holds.

In conclusion I must express my indebtedness to the Carnegie

Institution of Washington for a grant to carry on research on the heat treatment of iron and steel.

APPENDIX.

In the above paper the name Martensite has, for the sake of convenience, been used in its old meaning, the solid solution of carbon in iron or what is often termed mixed crystals. Now, however, the solid solution is known as austenite, and Martensite is a transition product. Recently Sauveur* has dealt with the subject and from his paper we learn that:—

Austenite is a solid solution of carbon in γ iron.
Martensite is a solid solution of carbon in β iron.
Troostite is a solid solution of carbon in α iron.

Pearlite is the iron-carbon eutectoid, in other words a mechanical mixture of ferrite and cementite. Thus austenite, Martensite, troostite and pearlite form a series, Martensite and troostite being transition products between the original solid solution and the eutectoid. Sorbite or the unsegregated form of pearlite would therefore occur between the latter and troosite.

BRITISH TRADE IN LATE YEARS.

The London *Statist* for February 9 says: "Two distinctly interesting features of the growth of our foreign trade during the last two or three years have been, first, the very large expansion in our exports to foreign countries and the relatively small increase in our exports to our colonies, and, secondly, the moderate increase in our imports of produce from foreign countries and the considerable expansion in our imports from our colonies. In three years the exports of the produce of the United Kingdom to foreign countries have expanded £74,770,000, or over 41 per cent., while the growth in our exports to our colonies has been only 9 per cent. In a period of two years and six months the expansion in the value of the exports of British produce has exceeded the expansion in our net imports by no less than £49,659,000. From whatever point of view these results are regarded no one can fail to be delighted that the trade of the country has expanded in this remarkable manner."

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*Journal of the Iron and Steel Institute, 1906, IV, 493.

Mechanical and Engineering Section.

(*Stated Meeting, held Thursday, March* 15, 1906.)

The Development of Street Pavements.

GEORGE W. TILLSON, Chief Engineer Bureau of Highways, Borough of Brooklyn.

Thirty years ago there was not a mile of pavement in existence such as is considered standard at the present time—it will therefore be of interest to study the causes which led to the use of the different materials in vogue at that time and also what led to the changes that have resulted in the adoption of the materials now in use.

It is said that the remains of an old road formed of broken stone have been found near the great pyramid in Egypt; this road was undoubtedly constructed for the purpose of carrying stone across the sandy desert for use in the construction of that pyramid. As this pyramid was built about 4,000 B.C. this road is unquestionably the oldest one on record. When the Romans invaded Africa for the destruction of Carthage about 150 B.C. they found a well established road system which aided them very materially in the mobilization of their armies. The practical use of these roads evidently led them to construct others in their subsequent invasions in European countries, as wherever they went they left a large extent of well constructed roads. Pavements proper, however, were not very much in use until later times. Rome had its first pavements in the 4th and 5th centuries after the founding of the city, and the first pavements in Paris were laid in 1184, when the city already had a population of about 200,000. The Strand, London, was ordered paved by an Act of Parliament in the 14th century when its population was 100,000. When it is considered that cities at the present time containing five or ten thousand people have a considerable amount of pavements, it must seem strange that these older cities existed so long with unimproved streets. The explanation of this is that besides

their lack of civilization, there was very little traffic carried on by means of wagons—most of it being done by means of pack-horses and other beasts of burden. It is said that in the reign of Queen Elizabeth only 420 carts were allowed on the streets of London—the merchandise all being carried on pack-horses; and one hundred years later trains of pack-horses were regularly started from London to different parts of England. In 1625, in a population of 265,000, there were only twenty hackney

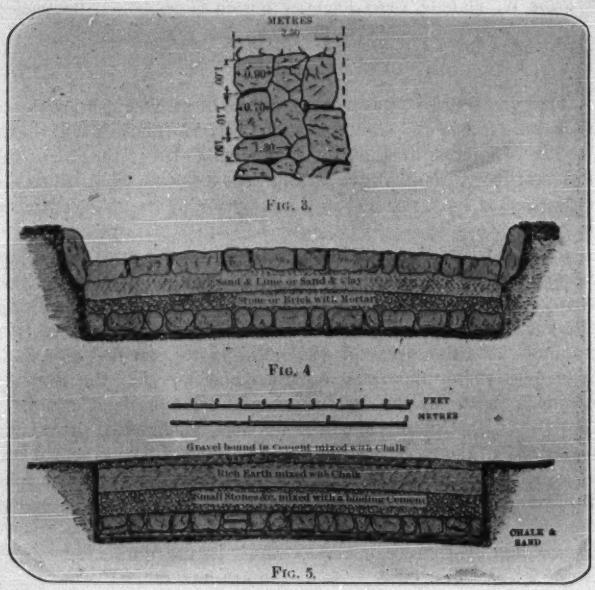


FIG. 3.

FIG. 4

FIG. 5.

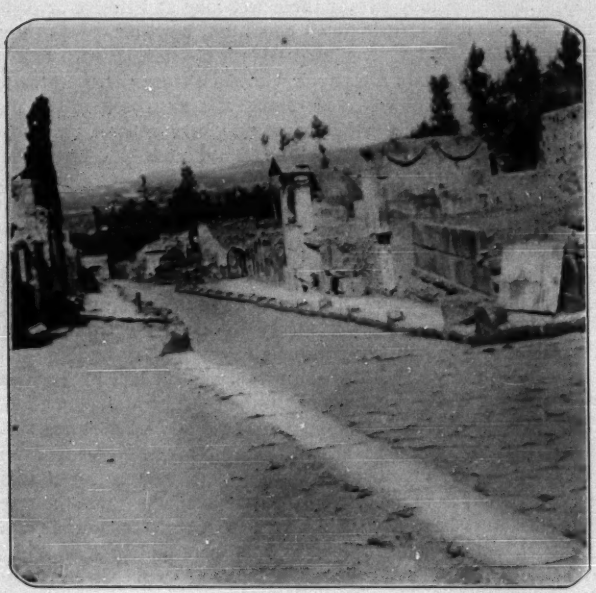
An Old Roman Road.

coaches in use. All traveling in France was done on horse-back until the latter part of the 16th century. In the city of Paris in 1550 there were only three carriages. The oldest pavements this generation has been able to see are those that have been disclosed by the excavation of the streets of Pompeii; the streets were narrow and the roadway was formed of large and irregu-

larly shaped stones, laid flatwise. These pavements are in a good state of preservation and are fair samples of work of that character done 2000 years ago.

As late as 1826 an engineer in London who had been investigating pavements on the Continent, wrote as follows:

"Florence, Sienna, Milan and other Italian cities have pavements with specially prepared wheel tracks. These tracks are



A Paved Street in Pompeii.

three feet in width, made of large and well laid stones. They are about four feet apart and the space between paved with smaller stones."

He also says these pavements as well as similar ones he saw in Rome are the best he has ever seen, but he adds that they are too expensive for London. When the relative importance of these cities and London at the present time are considered this state-

ment is very interesting. As a rule the early pavements were made of large and irregularly shaped stones, laid flat and with very little care. As traffic increased, however, the necessity of better streets became apparent and the character of the pavement gradually improved. The stones were selected with more care and shaped roughly so as to make a smoother surface. In Italy the development took the line of large flat stones, oblong in shape, approximately two or three feet long and twelve or eighteen inches wide. Such stones could not, however, prove satisfactory and were not long used where the traffic was heavy. Some streets in Italy are paved with such stones at the present time. The well-known cobble stone was also used in the development of pavements. It came into very general use probably on account of its availability and cheapness. As the development continued it resulted in the formation of what is known as the Belgian block. These blocks were so called because first used in Belgium, and were in shape practically cubical blocks. They make a very good and serviceable pavement, but are expensive. Following this came the oblong granite blocks such as are in use in our American cities at the present time.

The development of pavements in this country was practically the same as that in Europe, although very few of the large flat stones were used. Probably the first pavement laid in America was laid on a street in Pemaquid, on the coast of Maine, in 1626. This pavement has been unknown until recently when it was discovered by a farmer who in ploughing up his field met with an obstruction. On investigation a well defined paved street was discovered and from the best information available it was thought that this must have been laid about 1626; the material was cobble stone. Cobble stone pavements were laid in New York and Boston practically at the same time, viz: 1656. In the early days of New York the Dutch built several breweries on the road lying between Broad and Whitehall streets, which has since been called Brower street. The brewery wagons created such a dust that the wives of the good burghers made complaints and finally the roadway was paved with stones. The street was then known as the Stone street and it was visited as a curiosity by a great many people. Since that time the name has been changed to Stone street, by which it is known at the present time.

It is possible to trace the laying of pavements in the city of

New York quite completely. Cobble stones were used entirely until 1849 as the regular material, although a few wooden blocks had been laid experimentally in lower Broadway in 1835. In 1849 Broadway was paved as far north as Franklin street with what was known as Russ Blocks. These blocks were from two to three feet square and on grades were grooved in order to give better foothold for the horses. This pavement was relaid in 1868. In 1865 an experimental iron pavement was laid on Cortland street. This consisted of short cast-iron cylinders placed on end with the spaces between and the interiors of the cylinders filled with gravel. Other similar pavements to this have been laid with the spaces filled with cement concrete. As might have been expected, this pavment was not satisfactory.

The so-called Belgian blocks were laid for the first time on the Bowery in 1852, and came into general use in 1859. They were supposed to be, and were, an improvement over the old cobble stone pavement. It was soon found they would not make a satisfactory pavement and in 1876 the present well known granite blocks were used. What is known as the Guidet Patent Granite Blocks had been laid a few years previously. These blocks were practically the same as the granite blocks used to-day. Quite a quantity of this pavement was laid in Brooklyn in 1869 at a cost of about $7.00 per yard on a sand base. Although the patentee claimed royalty and brought suit against the city for the use of these blocks, the final decision of the court was against him and no royalty was recovered. The blocks were very large, some of them still remaining on one of the Brooklyn streets at the present time, being five to six inches wide and from eighteen to twenty inches long.

Asphalt in an experimental way was laid near the Battery in 1871. The condition of the New York pavements was such that a general scheme for their improvement was adopted in 1889, special legislation being obtained for issuing bonds for carrying out the work. From this time dates the beginning of the present improved pavements in New York city.

Cobble stones were used very largely in cities near the coast—Brooklyn, Philadelphia and Baltimore probably having the largest quantities. According to a bulletin issued in 1899 by the United States Department of Labor, Baltimore had 5,815,610 sq. yds. of cobble stone pavement, New York City 4,213,616 sq.

yds. and Philadelphia 2,920,664 sq. yds. This amount has been reduced in Brooklyn to 78 miles or about 160,000 sq. yds. (the other boroughs in New York City having practically no cobble stone pavements), and to 61.4 miles in Philadelphia.

In 1843 a committee of engineers was appointed by your own Franklin Institute for the purpose of investigating and reporting upon the best material to be used by the City of Philadelphia. After a careful examination this committee reported in favor of three kinds of pavements: the first to consist of dressed stone blocks, laid in diagonal courses, the blocks to be 8 inches deep, 7-9 inches wide and 8-10 inches long. This pavement was estimated to cost $3 per sq. yd. On streets of the second class the pavement was to consist of two stone tramways to accommodate traffic in both directions—the spaces between the trams and curbs to be paved with cobble. This pavement was estimated to cost $1 per sq. yd. The streets of the third class were to be paved with cobble stones. The committee reported as the best shape for the cobble stone: "They would be prolate spheroid generated by an ellipse of which the major axis is double the length of the minor." This report seems to have met with the fate of most such reports, as in 1884, forty-one years after its date, ninety-three per cent. of the entire pavements in Philadelphia were cobble stone—the entire length of the pavement being 535 miles. How closely the shape recommended by the committee was followed out in other cities is illustrated by a stone the speaker once measured in a Brooklyn street, which was 3 feet 10 inches long by 11 inches wide and he never learned how deep.

Wood as a paving material seems to have been used in this country in cycles of twenty years. During the forties wood was adopted quite extensively in Philadelphia, New York and Boston. No particular attempt was made to select suitable kinds or lay it in any special manner and the result was what might have been anticipated, very unsatisfactory, and its use was soon discontinued. In the sixties the well-known Nicholson wood pavement was used to quite an extent throughout the country and for a few years gave quite satisfactory results, but the uneven decay and wear of the wood soon caused the pavement to become rough, and it lost its popularity. In the eighties the cedar block pavement craze spread throughout the growing cities in the West, and many million yards of this pavement were laid. It was

only a make-shift pavement and in a comparatively few years was not seriously considered as a paving material and not used to any great extent except in Chicago. In the present decade the use of wood has again come to the front and it is not only being seriously considered, but has been generally adopted as a suitable paving material. It must be remembered, however, that it is a very different material from what has ever been used before, as not only the best quality of wood is selected, but it is treated chemically so that it will not decay, and the length of its life will depend upon the amount of traffic it sustains. This is the theory of the promoters, and present experience seems to justify their claims. Wood has been used in the larger cities of Europe for quite a number of years and there it is generally untreated. Pine and deal wood are used as well as hard woods imported from Australia. The conditions in these cities, however, are different from those in American cities, as the traffic in London and Paris is such that the blocks wear out before they decay, so they do not require to be treated chemically.

Asphalt was first used in any great amount in Washington, when Pennsylvania avenue was paved with it in 1876. The success of this pavement was such that it gradually grew into popularity; it is probable that during 1905 a greater mileage of this pavement was laid in the larger cities than that of any other kind. The accompanying table shows the changes in the character of the pavements in the cities of Brooklyn, Boston, Buffalo, Chicago, New York, Philadelphia, St. Louis and Washington. This table shows very plainly the popularity of asphalt as a paving material and also that of brick. It is undoubtedly true that if the smaller cities, in the Middle West especially, had been used as examples, a much larger proportion of brick pavement would have been shown. A great deal of experimenting has been done in trying to secure good pavements and the best material with which to construct them. In 1874 seventy-six patents had been issued by the Government for constructing pavements of coal tar, asphalt and other bituminous material, and pavements more or less successful have been laid in this country and in Europe of wood, asphalt, coal tar, cement concrete, iron, brick, India rubber, shells, gravel, slag blocks and even glass and hay. At the present time the following pavements are considered standard: Asphalt, wood block, stone block, asphalt block, brick, and bitu-

MILEAGE OF PAVEMENTS IN

Character of Pavement.	Brooklyn			Boston			Buffalo			Chicago	
	1890	1900	1906	1890	1900	1906	1890	1900	1906	1890	1900
Asphalt	10.85	68.82	263.48	4.65	13.80	21.16	106.03	222.74	228.71	9.24	78.60
Stone Block	83.90	159.95	186.53	69.27	86.97	96.34	140.69	104.50	98.91	23.10	29.77
Cobble	289.21	236.85	78.40	5.95	1.01	0.30	. . .	. . .	. . .	. . .	. . .
Rubble	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Brick	. . .	3.78	3.62	0.35	0.80	0.38	0.07	7.47	14.20		29.51
Macadam	2.81	78.57	99.81	204.57	280.57	337.10	3.28	3.08	11.90	227.01	363.40
Coal Tar and Concrete	. . .	. . .	. . .	BITULITHIC		5.00	. . .	. . .	. . .	. . .	. . .
Garnolithic	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Slag Block	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Wood	. . .	. . .	2.16	. .	. .	0.91	. . .	. . .	. . .	410.29	763.21
Miscellaneous	. . .	. . .	. . .	GRAVEL		33.57	. . .	. . .	. . .	. . .	4.88
Total	386.77	547.97	634.00	284.79	383.15	494.76	250.07	337.79	353.72	669.64	1269.37

TOTAL ASPHALT PAVEMENT

1890	1906
229.92	1367.15

N LEADING AMERICAN CITIES

ago		New York			Philadelphia			St. Louis			Washington		
00	1906	1890	1900	1906	1890	1900	1906	1890	1900	1906	1890	1900	1906
.60	271.43	16.34	162.44		43.40	254.10	379.69	3.95	11.81	41.87	51.80	129.27	*160.81
.77	48.47	278.75	272.73		119.60	352.20	378.60	42.46	50.36	62.88	23.50	27.19	25.99
. .	. .	3.33	1.10		375.10	69.20	61.40	. . .	. . .	. . .	11.50	11.31	9.68
. .	. .	. . .	. . .		115.50	43.30	. . .	. . .	. . .	. . .	. . .	. . .	. . .
,51	87.41	. . .	1.10		19.80	119.50	145.71	. . .	14.23	79.82	. . .	0.40	0.92
.40	490.54	24.23	113.12		88.80	193.50	273.34	290.08	351.92	BIT. 20.21	8.00	34.39	77.11
. .	. . .	. . .	. . .		. . .	. . .	. . .	. . .	. . .	. . .	38.21	14.08	. . .
. .	. . .	. . .	. . .		. . .	12.80	12.77	. .	. . .	. . .	. . .	. . .	. . .
. .	. . .	. . .	. .		. . .	5.60	9.82	. . .	. . .	. . .	. . .	. . .	. . .
.21	581.18	. . .	. . .		. . .	. . .	. . .	5.76	6.89	3.33	0.30	. . .	. . .
.88	6.54	. . .	0.08		. . .	. . .	. . .	. . .	. . .	291.01	. . .	. . .	. . .
9.37	1485.57	317.65	550.57		762.20	1050.20	1261.33	341.75	435.21	499.12	133.31	216.64	274.51

TOTAL BRICK PAVEMENT

1890	1906
20.22	332.06

*Includes coal tar.

lithic pavements. A large amount of macadam is being laid every year, but it cannot be considered a standard pavement.

Asphalt Pavements:—Asphalt pavements were first laid in the city of Paris—the first street being paved in 1854. These pavements were very popular in Paris, but were not entirely satisfactory on account of slipperiness. The European pavements were of a different character than those of this country. The former consist of asphaltic rock, which is taken from the mines, ground, then heated and transported to the street, where it is compressed by tamping and rolling so as to reproduce the origi-

Sheet Asphalt Pavement. Borough of Manhattan New York City.

nal rock as nearly as possible. The stone containing the asphalt is lime stone and for that reason the pavement is slippery.. The entire pavement must be transported from the mine to the plant and then to the street, so that the expense is comparatively large where the mines are a long distance from the streets to be paved.

The success of these European pavements, however, was such that experiments were made in this country in the sixties to reproduce if possible the European pavements, or something equivalent thereto. The original bituminous pavements were

made of coal tar, the first one probably in Brooklyn, in 1868. Washington laid a large amount of coal tar pavements, some of which are in existence to-day, having been down over thirty years. Coal tar, however, is not a stable or even material, and while some of these pavements were durable, others disintegrated in one or two years, so that coal tar as a paving material lost caste and asphalt from the Island of Trinidad was used as a cementing material. These original coal tar pavements consisted of sand and gravel bound together with coal tar.

Asphalt is a hard natural bitumen found in nature. It is quite generally scattered over the earth's surface. It is formed from petroleum oil in Nature's great distillery, requiring no one knows how long for its formation. It has been seen in California in every grade of its distillation from the crude oil to the hard asphalt.

Asphalt is also produced by the artificial distillation of these California oils and when the work is carefully done the resulting product is satisfactory.

The asphalt now in use comes principally from Venezuela, Trinidad and California.

In an asphalt pavement, asphalt itself forms only from ten to twelve per cent. of the entire pavement, the remainder being sand and stone dust. In almost every locality suitable sand can be found within a reasonable distance that would make cheap pavements, so that only ten or twelve per cent. of the entire pavements would have to be brought from a mine, thereby materially reducing the expense of the pavement to such an extent that European pavements cannot compete in cheapness with those laid according to the American methods. While not a perfect pavement by any means, asphalt appears on the whole to give the best satisfaction for residence streets at the present time, and it seems bound to be a very important factor in street pavements for the future. It is comparatively noiseless, easily cleaned and its smooth surface is pleasing to the eye. One of its principal disadvantages is its slipperiness under certain conditions. If, however, the pavement is kept clean, there will not be much trouble on that account, as the pavement when wet is not as slippery as when it is simply damp. The matter on the surface of the pavement makes it slippery rather than its composition.

Asphalt Block Pavement:—Another form of asphalt pavement

is constructed from blocks. The blocks were originally 4x5x12 inches in size and laid on a gravel base. This made an expensive pavement, and the blocks have gradually been reduced in size until now they are generally laid 3x5x12 inches on concrete base with half-inch cement mortar cushion. These blocks are made with an hydraulic press under pressure of about 5000 lbs. per sq. inch. They are used principally on grades and where the traffic is supposed to be too heavy for sheet asphalt. They

Asphalt Block Pavement. Borough of Manhattan, New York City.

make a good, durable pavement when the blocks themselves are good. It is obvious that poor blocks will not make a good pavement. Great care must be used in making blocks and a thorough knowledge of their manufacture should be had by anyone attempting to make them. Specifications for blocks have never been standardized, or even made definite. They should be made of good substantial rock, and so dense that they will not absorb an appreciable amount of water, and so strong that they will not break or crumble under traffic. The stone used should be trap rock as nearly cubical in form as possible and ranging in size

from that which will pass through a ¼-inch hole to the fineness of dust and so graded as to have as few voids as possible. The asphaltic cement should be of such a character as to bind the particles of the stone together, and in amount should be about six to eight per cent. of the entire mass. Such a block should have a specific gravity of not less than 2.45, and if properly made should not absorb more than one per cent. water when immersed for twenty-four hours. Asphalt blocks must necessarily be made at a central plant and transported from the plant to the street, so

New Medina Sandstone Pavement. Borough of Brooklyn, New York City.

that they are somewhat more expensive than sheet asphalt. The pavement has increased in popularity from year to year and a great amount is constantly being laid.

Stone Block Pavement:—Stone block pavements of to-day are laid practically of granite blocks, but in Rochester, Buffalo and Cleveland the sand stone from the Medina quarries, in the western part of New York State, is used and giving good satisfaction. The granite blocks are generally from 3½ to 4½ inches wide, 7 to 8 inches deep by 12 inches long; the Medina blocks

varying somewhat from this. The standard pavement is laid on a concrete base, the joints being filled with some impervious material. The custom in the vicinity of New York is to fill the joints with coarse gravel, the interstices of which are filled with coal tar. In some vicinities, however, cement grout is used for the filling both for granite and Medina sand stone. Tar and gravel were first used for filling joints in the pavements in London in 1869 and in Liverpool in 1872. Probably the first pavements of this character in this country were laid by the Dock Department of the City of New York in 1881. Stone pavements are laid where the traffic is heavy, and when laid as above described, should last twenty-five to thirty years.

Brick Pavements:—Brick was first used as a paving material in this country in Charlestown, W. Va., in 1870. These bricks were laid on oak planks, which themselves were laid on a bed of sand. The pavement proved quite satisfactory and brick were gradually adopted in other cities in the vicinity. In the central West where natural paving material was scarce and expensive to obtain they have become very popular, the clays of Illinois and Ohio being especially adapted for paving brick. The bricks themselves have been laid in a number of ways according to the traffic to be sustained and the ideas of the controlling officials. A common practice under light traffic is to lay a course of brick flat, bedded in sand, and upon these lay the best brick on edge. The best method, however, is to use a concrete base and have the joints filled with some impervious material. This can be coal tar, asphalt or Portland cement. Considerable trouble has arisen in many cases where Portland cement has been used by the expansion of the pavement and the rumbling sound, caused probably by the lifting of the pavement from the concrete. It would seem strange that brick which must have been submitted to a temperature of 1800 to 2000° F. should expand when laid in a pavement when the temperature of the air is but 120 to 125° F., but such is a fact, and the practice to-day is whenever cement is used for the joints to have expansion joints of asphalt or some other bitumen every twenty-five or thirty feet across the street and longitudinally against the curb. Brick pavements have not been used so much in the East as in the West, as the clays in the former section are not suitable for making paving brick and the expense of transporting them from the West is heavy. They make a

smooth but a more noisy pavement than asphalt, and in the East one that is more expensive. They have been used quite extensively in the smaller cities, but Philadelphia is the only large city in the East that has adopted them to any great extent.

Wood Pavements:—It may seem strange after what has been said that wood pavements should be considered a standard paving material, but when it is understood how different the present

Wood Pavement. Borough of Brooklyn, New York City.

wood pavements are from those of the past the apparent paradox will be explained. The first wood pavements were laid of spruce or hemlock, the material taken without any special care and laid in an ordinary manner. With the Nicholson pavements both the character of the blocks and the manner of laying had been much improved; the blocks being of pine and laid on planks which themselves were placed on a sand cushion. The cedar block

pavement laid in the West was simply formed of blocks six inches long cut from cedar posts with the spaces between filled with tar and gravel.

Some seven or eight years ago the officials of Indianapolis in considering wood pavements decided that if treated wooden blocks would make a good pavement anywhere they would in Indianapolis. They therefore laid pavements, treating the blocks with creosote oil, the specifications calling for 10 lbs. to the cu. ft. These pavements were quite satisfactory, but swelled when being exposed to water and sometimes bulged considerably. This was undoubtedly caused from the fact that the blocks were imperfectly treated and the creosote itself was probably of an inferior character, as later pavements laid in the same way, but with more care, gave good results. It was found, however, that the creosote being an extremely volatile material evaporated and left the blocks porous and subject to moisture. The problem then was to hold the creosote in the wood so as to prevent absorption of the moisture and yet obtain the preservative properties of the oil. The block known as the Kreodone block was then made and used with good success in Indianapolis. This block was treated with creosote and some other more stable substance, probably an asphaltic substance, which prevented the volatilization of the oil and thus preserving the wood. In the East another form of treatment has been adopted quite extensively, which is known as the Creo-Resinate process. These blocks are treated with a compound made of one-half creosote oil and one-half resin, 20 lbs. to the cubic foot being injected into the blocks. The idea of the resin is to preserve the creosote in the blocks and so preserve the block itself from decay. A pavement of this kind was laid on Tremont street, Boston, some six years ago, and now shows almost no wear, although it has been subject to quite heavy traffic. There seems to be no question that this form of pavement will be extensively used in the near future. It has been laid during the past year on several of the heavy traffic business streets of New York.

The pavement for which wood blocks are specially adapted is for the paving of bridges on account of its durability and its lack of weight. A well treated block should have a specific gravity of a little more than one. These Creo-Resinate blocks have been used on the new Williamsburgh Bridge across the East River

and after having been in use for two years show very little wear. Some three years ago a small bridge in Brooklyn was paved with these blocks where the traffic was so heavy that ordinary planking wore out in some six or eight months; the present pavement is in fairly good condition now and would have shown very little wear had the foundation been even and solid, but it was laid on the old planks, which were uneven and shaky, so that the blocks soon broke into small pieces, but as pavement as a whole main-

Macadam Street. Borough of Brooklyn, New York City.

tains its entirety. If the treatment of the blocks as described above will prevent all decay a pavement of this kind should last for many years on a resident street, and the proprietors of the pavement are prepared to apply it on the heaviest traffic streets. One great advantage of it is that it is the least noisy pavement of any in use. Its greatest disadvantage is its slipperiness. This pavement has cost in Brooklyn, having five years' guarantee, about $3 per sq. yd.

Macadam Pavements:—The macadam pavements are not standard and are too well known to require any detailed descrip-

tion. Their durability is governed wholly by the quality of the stone that is used in their construction. They are noiseless, easy for horses and cheap, but are extremely dusty, requiring constant sprinkling if they are to be kept in good condition. It would probably cost five or six cents per square yard per year to keep macadam pavements properly sprinkled, which is more than the average cost of asphalt in an ordinary good condition for total repairs. Attempt has been made to prevent dust on macadam pavements by treating the surface with coal tar. This has been quite satisfactory in many instances, but has not been tried sufficiently to afford basis for an intelligent opinion as to its durability. Another material for treating is known as Westrumite—a substance patented by a German named Westrum. This substance consists of asphalt, resin and some ammonia which is mixed with water and sprinkled on the street. The theory is that it will form a sort of gum and bind the dust together. This has been used somewhat during the past year but not enough to show just how practical it is. Some time ago a contractor in the East who had been connected with the laying of asphalt pavements took up the problem of improving macadam with coal tar. Strange as this may seem, instead of improving the macadam his labors resulted in the development of an entirely new pavement known as the Bitulithic Pavement.

THE BITULITHIC PAVEMENT.

This pavement was first introduced in the year 1901 in Pawtucket, R. I., on Park Pace, having a 3% grade, and on Harvey street, having a 12% grade. It is made of crushed stone and bitumen, the particles of stone being mixed in certain scientifically predetermined proportions as to sizes so as to provide a maximum of density and minimum of voids, so that the resulting bituminous concrete pavement is nearly as dense as a block of solid stone, with a surface that offers as little resistance to traction as asphalt, but one that is not slippery, because the fine stone used in the finish course provides a gritty surface similar to macadam, which affords secure footing for horses at all seasons.

The sub-grade for the Bitulithic is prepared as for other pavements, and the foundation may be either bituminous or hydraulic concrete, depending on the character and solidity of the sub-soil.

The concrete foundation is prepared as for asphalt except that when used with the Bitulithic wearing surface it is roughened by tamping crushed stone into the surface before the mortar has set so as to provide a bond and prevent the surface from rolling or creeping.

The bituminous foundation consists of broken stone or slag from two to three inches in size, laid to a depth sufficient to meet the demands of the traffic to which the proposed street may be subjected, usually from four to six inches. The broken stone is then thoroughly compressed with 15-ton road rollers. Over this compressed foundation is spread a coating of heavy bituminous cement, or binder, which serves to firmly unite the foundation and wearing surface.

The wearing surface, after thorough compression, consists of two inches of the hardest broken stone available, varying in sizes from one or one and one-half inches down to an impalpable powder, the various sizes of the smaller stone, sand and impalpable powder being provided to fill the spaces between the larger stones. The proportions of the various sizes of material used are predetermined by physical tests with a view to obtaining the smallest percentage of air spaces or voids in the mineral mixture, and vary with the character and size of stone used in each particular case. After the proportions have been determined, the crushed stone is passed through a rotary dryer, and is then mechanically screened and separated into six sizes. The proper proportion by actual weight of each of these sizes is run into a mixer and there combined with a bituminous cement, which is also accurately weighed in the proper proportion. After being thoroughly mixed, and each particle of the mineral aggregate properly coated, it is hauled to the street, spread and thoroughly compressed with heavy steam rollers.

While the compressed Bitulithic surface is still warm, a flush coat of quick drying bituminous cement is applied, thoroughly sealing it and filling all pores in the surface, thus preventing the penetration of moisture. There is then applied a thin layer of hot, finely crushed stone, varying in size from one-fourth to three-fourth inch in size, according to the degree of roughness desired in the surface. The pavement is again thoroughly rolled and the street is finished and at once ready for traffic.

The Bitulithic pavement has been laid in 102 cities in the

United States and Canada, ranging in climatic conditions from Glace Bay, Nova Scotia, to Shreveport, La., and from Portland, Oregon, to Atlanta, Ga., to the extent of over 4,000,000 sq. yds. —about 200 miles of street 30 ft. wide; it has been subjected to all classes of traffic in these varied climatic conditions and has successfully met the requirements in each case.

The different kinds of pavements having been considered, the next problem is the adopting of the one best suited for any particular street. An attempt has been made to study the properties of the different pavement materials so that they can be applied intelligently to any street when exact conditions are known. The following table gives the result of this study:

Characteristics for a Perfect Pavement.	Percentage	Granite A	Granite B	Asphalt	Brick	Belgian	Macadam	Cobblestone
Cheapness	14	2	4	4	3	5	7	14
Durability	21	21	17	15	13	17	7	15
Easiness of cleaning	15	11	8	15	12	7	5	2
Light resistance to traffic	15	7	6	15	12	6	6	4
Non-slipperiness	7	6	5	3	6	3	7	5
Ease of maintenance	10	10	7	6	6	7	3	2
Favorableness to travel	5	3	2	5	4	2	5	0
Sanitariness	13	9	7	13	11	5	5	2
Total	100	69	56	76	67	52	45	44

In this table the characteristics of a perfect pavement are given in the first column and in the second the different values of each characteristic. The following columns show the values for the different kinds of pavements—Granite A is a granite block pavement, laid on a 6-inch concrete base with tar and gravel joints. Granite B is the same pavement, but laid on sand with sand joints. As the table was made some years ago, wood does not appear, but the different materials illustrate the principles of its operation.

The application of the above table can be illustrated in several ways.

Assume for instance a street over which the traffic must be

heavy and continuous. Ultimate cost is of great importance. It overrules first cost. Light resistance to traffic and foothold for horses are ruling elements, so that a given power may move its maximum load. The items first to be studied are, then: Durability, maintenance, traction, and the non-slippery property. Consulting the table and combining the values of these items, granite A has a value of 44; granite B, 35; asphalt, 40; brick, 37; Belgian, 33; macadam, 23, and cobble stone, 26.

Consider next a residential street, built up with homes whose owners have means sufficient to afford the best of anything they desire, and, while not wishing to be extravagant, do want and expect the best pavement that can be laid without regard to expense. This is an entirely different proposition. Cost, durability and maintenance, so important before, can be left out of consideration altogether. Easiness of cleaning, non-slipperiness, favorableness to travel and sanitariness are the governing characteristics. Working as before, granite A has 29; granite B, 22; asphalt, 36; brick, 33; Belgian, 18; macadam, 12, and cobble, 9. Asphalt possessing all the desired properties in so high a degree should be selected without much question.

It is also important to know just what each pavement will cost after it has been laid. Let C equal the cost per square yard, I equal rate of interest to be paid, N equal the life of pavement, R equal the total cost of repairs, and A the amount to be paid in each year to create a sinking fund to equal C in N years.

$$A + CI + \frac{R}{N} = \text{annual expense.}$$

For granite A: C = \$2.50:
I = .035;
R = .60 — an amount sufficient to relay the pavement once during life;
A = .064;
N = 25 years.

Substituting in the equation,

$$\$0.06425 + .0875 + \frac{0.60}{25} = \$0.17575 \text{ for first period.}$$

For the second period, assuming the value of the concrete to be \$0.70 per square yard, making the cost of relaying \$1.80 per

yard, the annual expense is found as before to be $0.13326, or for fifty years an average of $0.154.

In this way the actual cost of a permanent pavement of any kind can be determined.

It is often desirable to know positively when the cost of repairing a pavement has become so great that it would be economical to relay the pavement. This can be determined by the same formula, as its result governs the cost of maintaining the pavement perpetually, so that when the annual repairs equal or exceed the perpetual annual cost, it is time to repave.

Take for instance an asphalt pavement, and let N = 15 years, C = 1.50, I = 3½ and R = 0.40. Then A will equal .0807 and the equation becomes $0.0807 + .0525 + .0267 = $0.1599; or if the street be repaved it will cost annually $0.16 till it is renewed. Consequently if the life of asphalt be correctly assumed at 15 years, it should not be repaved until the annual cost approaches $0.16 per square yard. Assuming the life to be 20 instead of 15 years and applying the formula as before, the annual cost will be reduced to $0.1356 per yard.

The author believes this is the true scientific way in which to determine when an asphalt pavement, from an economical standpoint, should be relaid.

ALUMENUM COATED SHEETS.

A comparatively new product, named Alumenum coated steel sheets, is now coming into prominence for a large number of purposes for which sheet metal work is used. This material stands relatively between galvanized iron and copper, being better, it is said, than the galvanized iron and not as expensive as sheet copper. It has been tested for some years under most trying conditions with highly satisfactory results. The two most important qualities in sheet metal working are fully met, in that it will double seam without scaling and will solder freely. Alumenum coated sheets are used largely for tanks of various kinds, reservoirs, boilers, furnace and smoke pipes, oven linings, flues, &c. In the automobile trade its use for hoods, fenders, and bodies as well as for cylinder jackets and various other parts is becoming quite large. These sheets are rustproof, retain their color, and the coating will not peel off, even when subjected to a high degree of heat. A Philadelphia firm is placing on the market the original Alumenum coated steel sheets, which it is making in all gauges from Nos. 10 to 30, standard sizes being kept in stock, while special sizes are made to order.—*Iron Age.*

Section of Physics and Chemistry.

(Stated Meeting held Thursday, March 28th, 1907.)

Theory of Dyeing.

J. Merritt Matthews, Ph.D.

Dyeing is essentially a process of coloring substances. In a limited sense it is usually taken to refer to the coloring of various textile fabrics, though broadly speaking it is not really limited to any definite material. We have not only the dyeing of textile fabrics, but also the dyeing of leather, paper, wood, feathers, horn, ivory, marble, confectionery, food-stuffs, wines and liquors, soaps, candles, straw, eggs—and coming down to more human elements, even the hair and complexion of the weaker sex lend themselves as fit materials for the practice of the dyer's art; and even our own flesh, heir to many evils, is not immune from the tatooer's colors. Dyeing, however, does not include every operation of coloring substances. A proper distinction must be made between dyeing and painting; in the latter, a color is applied to the *surface* only of the substance, either for the purpose of artistic ornament or as a protection; in dyeing, however, it is the material itself of the substance that is colored, not merely the surface. Even in the printing of fabrics, the operation is essentially a dyeing process, the fabric (or other material) being dyed in places only; and a distinction must here be drawn between textile printing and printing used in the sense of book or paper printing, which is only the application of a pigment to the surface and would come under the general term of painting, using blocks of type instead of brushes.

Dyeing is also to be distinguished from painting in that it applies color through the medium of a solution of the coloring-matter; whereas in painting the coloring-matter is an insoluble pigment held in suspension in a suitable liquid medium. The application of the color in painting is essentially a mechanical operation; in dyeing, however, the application of the color usually involves

rather complicated chemical processes, and is itself more or less of a chemical reaction.

Though this general conception of dyeing is rather well understood, there is, nevertheless, a great deal of confusion existing concerning the exact nature of the phenomena which deals with the dyeing process. Many different theories have been advanced concerning the relations between the dye-stuff and the substance dyed, but though many of these theories may explain certain examples of dyeing, none of them offer a satisfactory and complete explanation of the whole general field of dyeing. This may be accounted for by the fact that the dye-stuffs employed are of varied chemical composition and properties, and a theory which would satisfactorily explain the behavior of one dye-stuff would be wholly inadequate to explain that of another possessing entirely different chemical characteristics. Furthermore, if we confine our attention even to the sole consideration of the textile fibres as the substances to be dyed, we meet with wide variations in chemical characteristics as well as differences in physical properties and structure; and hence, it may easily be understood that a theory which would explain the manner of applying dye-stuffs to one fibre would not necessarily be the proper one to explain the dyeing of another kind of fibre. Wool, for example, is very different from cotton in both its chemical characteristics and its physical properties, and though a chemical theory of dyeing with respect to wool with acid and basic dyes might be quite acceptable, nevertheless, it would not serve in any manner to explain the relation between cotton and the substantive dyes.

The process of dyeing, in the first place, must be viewed with reference to the nature of the dye-stuffs. These are capable of classification under rather well defined groups, which are as follows:

(1) *Acid dyes*, or those in which an acid nature is characteristic. These are to be considered as salts of certain organic acids (color acids) with such bases as soda or potash. They are usually dyed in a solution acidified with sulphuric or acetic acid, and are readily taken up by the animal fibres, wool and silk; but exhibit little or no attraction for the vegetable fibres, such as cotton and linen.

(2) *Basic dyes*, or those in which a basic nature is characteristic. They are considered as salts of certain organic bases (color

bases) with such acids as hydrochloric and sulphuric acid. They are usually dyed in neutral baths and exhibit a strong attraction for the animal fibres, though but little for the vegetable fibres.

(3) *Substantive dyes*, which appear to be of a neutral chemical character, and are derivatives of benzidine or other diamine compounds. They are dyed in a neutral solution, and show an especially pronounced attraction for the vegetable fibres, though they also dye on the animal fibres, in many cases just as well.

(4) *Mordant dyes*: these are also of a neutral character, but possess the property of forming insoluble color-lakes with metallic bases, like the oxides of iron, chromium and aluminium. They are mostly derivations of anthracene and analogous bodies. They show no true dyeing properties towards any of the fibres, but require a proper mordant.

(5) *Pigment dyes*, consisting of insoluble pigment usually precipitated within the cells of the fibres by double decomposition between two soluble salts, such as the dyeing of chrome yellow. These pigments are mostly of a mineral nature.

(6) *Vat dyes*, such as indigo, aniline black, and a few others of minor importance. The insoluble coloring-matter is usually formed by oxidation of some compound absorbed in the fibre.

These six classes, I believe, will include about all methods of dyeing which are liable to be encountered. It will be noticed that the acid and basic dyes exhibit well defined chemical characteristics, and as they dye only the animal fibres to any extent, it is supposed that they enter somewhat into a chemical combination with the fibre. That is to say, the acid dyes combine with the basic constituent of these fibres and so form color-lakes of a definite chemical function. And as these animal fibres also possess acid characteristics, they furthermore combine with the basic dyes in a similar manner. To what extent this chemical union between the fibre and the dye-stuff determines the power of the coloring-matter to dye the fibre, is open to question; that it is the sole factor in the dyeing process, however, cannot be substantiated, though there is no reason to doubt but that it exerts considerable influence in giving, at least, *direction* to the dyeing reaction. This chemical theory cannot be applied to the dyeing of

the substantive colors, either on the vegetable or animal fibres, and we must look for a broader and more general conception to include this class of dyes.

If we view the fibres as gelatinous substances, such as a stiffened jelly or glue, we can conceive of the possibility of them being able to dissolve substances within themselves, forming as it were a solid solution. A broad conception of dyeing is to consider the dye-stuffs as actually dissolving in the substance of the fibre, hence the process of dyeing may be said to be a phenomenon, primarily dealing with solutions. Gelatinous substances, though they are really solid, also seem to possess some of the characteristics of liquids, especially with reference to their power of dissolving substances. Starch paste, jellies made from vegetable gums, or animal gelatine or glue, all have the power of dissolving various substances, such as metallic salts and dye-stuffs. Hence it may be perfectly proper for us to say that silk, wool, and cotton are capable of *dissolving* mordants and dye-stuffs in the same general manner that any other solvent would. The affinity of a dye-stuff for a fibre becomes nothing more than the power of the fibre to dissolve the coloring-matter out from its solution in water—in which form the dye-stuff is applied. When the fibre has a strong solvent action on the coloring-matter we say it has a strong "affinity" for the dye-stuff, and if its solvent action is only slight, we say that the "affinity" is weak. The study of the theory of dyeing then becomes a study of the sets of relations between the fibres and water, on the one hand, as solvents, and the dye-stuffs and mordants, on the other hand, as the substances dissolved, and this comes within the strict province of physical chemistry and the theory of solutions.

The animal fibres, wool and silk, as a rule, exhibit solvent properties which are very similar; and on the other hand, cotton, linen, and the vegetable fibres in general, appear to exhibit similar properties in this connection. This may no doubt be conditioned very largely by the chemical nature of the two classes of fibres, though we also have instances where there appears to be distinctive properties between wool and silk. Silk, for instance, may be dyed with indigo carmine from an acidulated bath, and takes up the color quite readily; but if a mixture of silk and wool be dyed in such a solution, the wool takes up the color almost exclusively, the silk only becoming slightly tinted. This

is explained by supposing that the wool dissolves the dye-stuff much more readily than the silk.

There are several factors which may influence considerably the solvent action of the fibre for the coloring-matter. One of the principal of these is heat. As a rule, dyes are much more soluble in the fibres at a boiling temperature than at lower ones; on this account the dyeing process is mostly carried out in a boiling solution. Wool, for instance, if dyed in a cold solution of naphthol yellow will take up but little color; but in a boiling solution of this dye-stuff the fibre becomes colored an intense yellow. The addition of various chemicals may also influence considerably the solubility of the coloring-matter in the fibre. In the case of the general class of acid dyes, the addition of sulphuric acid to the dyebath may be considered as greatly facilitating the solubility of the dye-stuff in the animal fibres. In some cases, the addition of alkalies somewhat increases the solubility of the coloring-matter in the fibre; this is the case with certain substantive dyes in relation to the cotton fibre. The addition of such neutral salts, like common salt or glauber salt, also effect this purpose. The action of these additions to the dyebath will naturally vary with the chemical nature of the substance added; in some cases there may be a chemical reaction with the dye-stuff leading to the formation of compounds which are more soluble in the fibre. In the case of acid dyes, the dye-stuff itself is a salt of a color-acid; when sulphuric acid is added to the solution, the salt is decomposed with the formation of free color-acid, and this latter compound is more soluble in the fibre than the color-salt, hence the addition of sulphuric acid causes the fibre to be dyed more deeply. In some cases there may be no chemical reaction with the dye-stuff, but the increase in the dyeing properties may be due to other causes. When common salt, for example, is added to the dyebath with substantive dyes, it does not effect any decomposition of the dye-stuff; it does, however, greatly diminish the solubility of the dye-stuff in water, which results in a proportionately large increase in the relative solubility of the coloring-matter in the fibre.

The proper discussion of all the various factors entering into the theory of the dyeing process would be far too extensive and technical for me to consider in this brief review of the subject; but to show you in some manner the wide ramifications of this

matter, I will sum up the following factors which may be said to enter into the question at one stage or another:

(1) The *solution* factor, which may be defined as the difference existing between the degree of solubility of the dye-stuff in water and its solubility in the substance of the fibre. This may be called the "affinity" of the dye-stuff for the fibre.

(2) The *fibre* factor, depending on the nature and condition of the material being dyed.

(3) The *dye-stuff* factor, depending on the chemical nature of the dye-stuff used.

(4) The *chemical* factor, which includes the influence of any chemical reaction which may occur between the fibre and the dye-stuff.

(5) The *temperature* factor, which describes the effect of the temperature of the bath on the relations between the dye-stuff and the fibre.

(6) The *salt* factor, which relates in a similar manner to the effect of the presence of certain neutral salts in the bath on the dyeing process.

(7) The *mordant* factor, or the influence of the presence of certain metallic compounds in the fibre on its affinity for the dye-stuff.

(8) The *capillarity* factor, a physical property of the dye solution which has to do with the force with which this solution is mechanically absorbed by the fibre.

(9) The *osmosis* factor, another physical relation between the dye solution and the fibre, it representing the force with which the dissolved dye-stuff tends to pass through the cell-wall of the fibre.

(10) The *concentration* factor, depending on the strength or concentration of the dyebath with reference to the amount of dye-stuff in unit volume of solution.

(11) The *bath* factor, or the ratio between the amount of substance being dyed and the amount of dye-liquor.

(12) The *surface-tension* factor, existing between the dye solution and the colloidal substance of the fibre.

(13) The *dye-stuff mass-action* factor, being the influence of the relative amounts of two or more dyes in the same bath.

(14) The *fibre mass-action* factor, or the influence of the relative amounts of two or more fibres in the same bath.

ELECTRICAL SECTION.

(*Stated Meeting held Thursday, February 21, 1907.*)

Recent Developments in Wireless Telegraphy.

Dr. Lee de Forest.

No single subject before the world to-day is more typical of the speed and spirit of the times than the brief history of the Wireless Telegraphy.

Already we have progressed so far in the development of this science that it can be classified under several heads. Its leading exponents as a class considered highly specialized must already themselves specialize in the several branches of the new art.

There are investigators who devote their entire attention to the perfecting of the transmitting apparatus; others are authority on syntonization and methods of measurement; another class has specialized on receivers; others in the refinement of the mechanical details on which to a considerable degree the commercial success depends.

The bibliography of the Art already embraces nearly a thousand volumes and pamphlets, and a portion of the contents of most of our technical journals is devoted each week to "Wireless" items.

In these nine years since the first actual application of Hertzian wave telegraphy we have seen every navy equipping its more important vessels, each government starring its coast-line with stations of great or little power; the armies of the leading powers equipping their kite and balloon corps with field sets, and twice now the great powers have convened in International Conference to frame regulations and codify laws whereby the development and operation of this young science may be wisely directed or paternally regulated.

But surely this progress is not entirely accounted for by reference to the intense commercial competition of our times. There is a fascination in the task which stimulates—an etheric "call of

the wild" which has spurred us on, such as workers in few fields can hear.

In poor and painful beginnings, conceived of small knowledge and great faith, we have heard faint voices persistently calling. In the patience and poverty of humble laboratories we have seen visions and dreamed dreams. Then too the humanizing element of such work has not been lost sight of. It is a pride to know that to-day the distant mariner, lost by a hundred horizons, may hold converse with his haven by means of a small instrument and antennæ such as his ship can carry; and that when night has hidden even the waters of the sea-world from his view, this wireless voice reaches farther than by day, for thus kind Nature rules; so that a passenger off the southern coast may sometimes hold converse direct with home cities, far inland, even to Cleveland or St. Louis.

Latest and most novel of all branches of electrical science, Wireless Telegraphy has outstripped its keen chroniclers and found the printing-press a laggard; so that to-day, with scarce a dozen worthy exceptions, most of the treatises are already out-of-date.

We no longer look with interest or patience upon the chapters of a host of histories detailing the coherer, the "jigger," the simple antennæ, spark-gap and interrupter, the Morse printer, and a whole curiosity shop of other devices which not five years ago were seriously considered as embracing the essentials and the horizon of Wireless.

That famous log of the Italian man-of-war "Carlo Alberta," by Lieut. Solari, and its more interesting and equally veracious "Supplementary Log," by Mr. Maskelyne, have long ceased to astound or amuse.

In the text-books of the schools is recognized the position which this newest branch of electrical development has acquired; and although too many of our professors deem their duty done when the Branly filings-tube and the simple transmitter are described, yet the student is thereby given at least an inkling of the possibilities awaiting those who will qualify to enter in earnest this fascinating field.

It is obviously futile then to attempt in this brief paper a description of any but the most recent of developments in Wireless, and I shall in dealing with these, take it for granted that all

of my hearers are abundantly familiar with the last century apparatus. And I will only mention the good old days when Finlay and Willoughby Smith, Preece and Lodge toiled with conduction and induction methods, and Dolbear, employing excessively low frequency vibrations, first used elevated conductors at sender and receiver.

Popular interest has ever been centered upon the development of the receiving device. It is a striking commentary upon the keen competition in our electrical fraternity that since the limitation of the coherer, and the auto-coherer, or microphone receiver, were recognized, no less than six different genera of receivers have been discovered or made commercial, each of these classes differing from all others, not in detail of construction, but in the fundamental physical or chemical principle involved in its operation.

Some time lag was required for the ideas of certain pioneers to become "decohered"—They would stick to the filings and the tapper, the printer with the slow speed and the guess work inseparable therefrom; but the demonstration of the manifold superiority of a detector automatically restored to sensitiveness, the telephone receiver available therewith, the rapid and accurate sound reading by competent Morse operators—was too emphatic to long fail to convince.

First after the microphone, or auto-coherer, (itself extremely sensitive but equally erratic in operation) came the various forms of "anti-coherers," devices where either by the fusing of minute metallic bridges (Schaeffer plates) or by the same immersed in electrolytes and disrupted by gas bubbles, the local current was interrupted by the Hertzian waves. All of these, while at times marvelously sensitive, lacked reliability.

The magnetic detector was next produced; regular in action in certain of its forms, but lacking in sensitiveness, and inefficient. The bolometer, or hot-wire "barreter," utilized heat-energy of the received oscillations to raise the resistance of a platinum wire of microscopic diameter. This was moderately sensitive, beautifully adapted to quantitative measurements, but, alas, so ephemeral! A lightning storm in the next hemisphere seemed most disastrous to this molecular thermometer.

The electrolytic responder (appropriately described as the "polariphone," because it depends for its operation upon the

effect of the electric oscillations upon the polarization at the minute electrodes) marked a great step in advance over all existing detectors. Its sensitiveness is considerably greater than all preceding types, its electro-static capacity is quite constant and, especially when the fine electrode is glass-jacketed and its exposed end immersed well below the surface of the electrolyte, this detector is reliable, and requires no adjustment.

Another class of oscillation detectors utilizes the peculiar electrothermic qualities of crystalline or pseudo-crystalline substances, notably silicon and psilomelane. Silicon may be used without a local battery. The unequal heating effect produced by the oscillation at the junction between silicon and a copper electrode gives rise to feeble local currents which can operate the telephone receiver, to produce an audible signal.

This class of receivers is certainly the simplest and least costly imaginable, and marks an approach towards that Utopian state of affairs so much heralded by the popular press when each of us will carry a responder in his vest pocket, a telephone on his head; and with steel-rod umbrella in his hand, and lead soles upon his shoes, shall be within telephone reach of every other unfortunate similarly equipped!

The sixth type of receiver of which I speak employs neither solid nor liquid as its wave-responsive element, but gas, more or less attenuated and rendered conducting by heat, or electrical excitation, or by a combination of both. The gas flame, the heated vapors in an arc, or about an incandescent lamp filament are examples of a gaseous medium extremely sensitive in its current-conducting qualities to the influence of the electrical pulsations. The name, "Audion," is now generally accepted as descriptive of this class of Wireless receiver. In sensitiveness, reliability, and extremely close tuning qualities, it excels even the electrolytic responder.

In contrasting the relative refinements attained to-day in transmitting and receiving apparatus, Eichorn well says: "If the sender had anything approaching the ideal properties of such a highly developed receiver, the sphere of Wireless Telegraphy would be capable of far wider extension than now possible."

While laboratory research has been so occupied exploring the range of physics for a new and better wireless receiver, the mathematicians and pure-theorists have been little less busy in

developing methods of measurement, and in the analytical investigation of the laws involved in transmission and syntonization.

Max Wein, Abraham, Drude, Slaby in Germany, Poincare in France, McDonald and Fleming in England, and Pierce in America, have delved more or less deeply into the application of Maxwell's theory to the intricate and intensely interesting phenomena observed or to be expected.

Unfortunately the pressing demands of commercial development have allowed the practitioner in the field, who alone has the management of apparatus or facilities adequate for testing these theories, little opportunity for such research work. He is too often driven to the "cut-and-try" method, and many important questions of theory have gone unanswered; problems whose actual solution would doubtless greatly clarify our ideas and lead to improvements of utmost commercial value.

For example, aside from the brilliant but far too limited research work in measurements by Duddell and Taylor in England, of energies actually received with various arrangements of antennæ and earth connections, almost no progress has been made towards actually plotting the fields of force of these waves and the manner of their propagation.

Their work has pretty well established that the energy of the electro-magnetic wave varies inversely between the first and second power of its distance from the source. The wave, therefore, must expand not as the surface of a hemisphere, but of a hemisphere very much flattened. They have established the correctness of the theory, first advanced by Taylor and later by Blondel, that the feet of the electric lines of displacement are grounded to the conducting surface and slip along in the form of minute currents over the gradual irregularities of this surface, while the displacement lines, themselves nearly perpendicular to the earth's conducting surface, will cut through obstructing masses if these be non-conductors, but be reflected from or absorbed in eddy currents within the surface of *conducting* obstacles.

Many observed paradoxes in the transmission by Hertzian waves are thus made clear, but an enormous amount of data must be collected by costly experiments, some to be conducted in the upper atmosphere, before the complete theory of every-day transmission under great varieties of condition can be framed.

One great desideratum which has been before us from the first

is the discovery of a method whereby the propagation can be limited to any desired direction, thus greatly increasing attainable distance, and enormously simplifying the problems of mutual interference.

The original parabolic reflector of Hertz offers a clear solution but greatly limited in distance attainable, owing to the enormous dimensions which such a reflector for long waves would require.

The horizontal wave-chute or artificial ground net is yet unable to solve the problem. Prof. Braun has done some intricate and extremely pains-taking work with his system of several vertical transmitting antennæ, the currents in these being properly displaced in phase, so that their resultant wave is intensified in certain directions and neutralized in others. The accuracy demanded by this method has thus far prevented its successful operation.

Quite recently considerable attention has been drawn to experiments with the horizontal antennæ lying near the earth's surface both for receiving and sending. It has been found that the maximum distances of transmission with such antennæ lie in the direction of the horizontal wires, but these distances are enormously less than those attained with the same length of vertical antennæ. A compromise between the two is the oblique transmitting antennæ, inclined say at an angle of 30° to the earth's surface, and lying in the vertical plane which passes through the receiving station.

The writer began experiments with such antennæ in 1902, and since then has demonstrated the surprising extent to which masses of horizontal conductors, such as groups of telegraph wires and railroads, act as wave chutes to confine a large amount of the radiated energy to a zone co-axial with such lines. It is by virtue of this effect that the surprisingly long distances in transmitting wireless signals to moving trains are attained.

In certain work carried on at Chicago and St. Louis, in 1905, messages were clearly received on board express trains of the Chicago and Alton Railroad when at full speed, 35 miles from the transmitting stations.

Even when the telegraph wires were broken down and lying along the roadside, they, in conjunction with the iron rails, act admirably as wave conductors. And herein lie possibilities of utmost value to railroad companies to enable train-dispatching and

other telegraphic service by means of "Wireless," when the inevitable sleet storms have paralyzed the wire service.

But the great problems of non-interference must look to a perfection of syntonization or tuning devices, rather than to unidirectional transmission, for their solution.

To accomplish this, so that any two of say a hundred near-by stations may be in communication without interference from the others, is theoretically simple; actually and commercially difficult.

To-day all recognize the value of the so-called "loose coupling" between oscillating and radiating circuits, whereby there is radiated a fairly persistent wave train of but a single, well-defined period. The best known circuits accomplishing this result to-day are embraced in the Stone system. If the four distinct circuits represented by the oscillating circuit and the antennæ, both at sending and receiving stations, are closely tuned to a single frequency it is possible to prevent interference from a foreign oscillation if its frequency differs by only one per cent. from the oscillation to which the four circuits are attuned, even though this foreign oscillation have an intensity fifty times that of the other.

This degree of selectivity is ample for all the commercial demands which Wireless Telegraphy will be called upon to meet for some time to come. But it is yet too early to say that we to-day anywhere actually carry on uninterrupted communication between any two of a hundred neighboring stations. For no matter how loosely coupled an oscillating circuit and its antennæ circuit may be, the trains of waves sent out from any oscillator utilizing the ordinary spark discharge are too rapidly damped to allow of the full benefits which this loose coupling should confer.

If the wave train is sufficiently persistent it is, of course, possible to so far separate the receiving circuit from its antennæ-earth circuit that no impulses received on the antennæ can awaken response in the detector circuit except those long continued rythmic pulsations with which the responder circuit is in absolute resonance.

To substitute for the old-fashioned, easily obtained spark discharge, an oscillator which shall receive from the source of power new supplies of energy exactly as fast as radiated; in other words, to substitute in Wireless Telegraphy a sustained organ-note in place of a damped piano-string or tuning fork vibration,

has long been desired. But attention of experimenters has been too much directed upon other features of the non-interference problem.

Duddell's work, in 1900, with the singing arc marked a giant stride towards this goal; but Duddell and the German physicists, some of whose work, less widely heralded, I believe preceded his experiments, were unable to generate oscillations from a direct current arc of sufficiently high frequency to be available in Wireless work.

They fixed 50,000 or 100,000 vibrations per second as the upper limit of frequencies attainable with the direct current arc in air. With oscillations of such enormous wave-lengths as this implied too small a proportion of the energy was radiated.

Poulsen by enclosing the singing arc in an atmosphere of hydrogen succeeded in enormously increasing the frequencies. The presence of hydrogen, however, is not a *sine qua non* in the generation of useful oscillations from such source.

It is not essential in order to secure all the benefits of closest possible tuning, that the wave train is absolutely undamped or continuous. It suffices if there be say 100 oscillations in the train before the current amplitude falls to one-half of its initial magnitude. The wave train from a single spark-discharge however may represent only ten or twenty oscillations. The damping factors of the receiver oscillating circuit, representing the ohmic resistance and losses in the wave-detector, determine the limit beyond which there is no increase of effect no matter how long continued the wave train may be.

Given either a continuous radiation of un-damped waves, or a radiation of damped wave-trains in groups whose frequency is above the audible limit, or at least above the frequency of the more essential tones used in human speech—and Wireless Telephony over commercial distances is comparatively easy of realization.

For a long time it was recognized that the receiver side of the problem was already solved. In 1899 when the writer, using an automatically restored responder, first heard in the telephone receiver in circuit therewith the sound of the transmitter spark, he recognized at once that every acoustic property of that spark was being faithfully reproduced in the receiver. If the spark varied in frequency, or loudness, spluttered or hissed, the fact was as

readily manifest in the telephone receiver as to the ear of one standing alongside the spark. In fact, if a glass chimney was put around the spark, as a muffler, the observer at the receiver recognized at once the same ringing, metallic sound thus produced. I remember this was most forcibly again brought to my attention when the spark at the Key West station was similarly muffled, although the listener was many miles distant!

It was recognized from the first then that to achieve Radio-Telephony by means of Hertzian waves, with the same apparatus and over distances at least comparable to those in Wireless Telegraphy, it was only necessary to "teach the spark to talk!"

The medium required for the transmission of radio-telegraph signals is ether at rest; that for radio-telephony signals is ether in a continuous state of vibration. And upon this normally uniformly agitated medium it is necessary merely to impose variations of disturbance. But the same result is obtained, as expressed above, if the normal disturbance, instead of being absolutely continuous, is alternating with periods of quiet, so rapidly that no resultant sound is heard at the receiver.

Now, to vary the state of normal disturbance in the ether, it suffices to vary the intensity of the spark itself, which is the origin of this disturbance, or to vary the intensity of the high frequency currents which are surging from the antennæ into the conducting surface of the earth. At this point of attachment to the earth the current densities are greatest, the potentials are least, and this point is therefore the most sensitive and effective place in which to insert the intensity-governing device. This is the method on which I am now at work.

In small sets it is sufficient to insert a microphone transmitter directly in this earth connection, and to talk, not too loudly, therein. For larger power this microphone should be replaced by other speech-varied resistance devices.

In radio-telephony the problems of tuning to prevent interference, etc., are the same as in the telegraph, with the notable exception that with signals of equal strength it is easier to follow the words of a voice through all manner of static and other disturbances than it is the monotonous signals of a telegraph code.

The radio-telephone has a wide field in all marine communication, between isolated points in mountain and rural districts, in military field operations, and wherever there is a relatively limited number of simultaneous conversations to be carried on,

or where it is undesirable or impractical to employ two Morse operators.

It would be rash, at this time, to attempt to predict its limitations as to distance. Inasmuch as it employs the same methods of transmission as Wireless Telegraphy it is certainly plausible to expect distances one-third or one-half as great by the Aerophone, as soon as one has learned to control by the voice the same amounts of energy as are now required in telegraphy; it being understood that with the Aerophone the maximum range can not well be greater than that over which the *weakest* impulse represented in the speech waves can produce an audible effect.

Time works vast changes in our performances and estimates nowadays. Witness especially how our wildest dreams of attainable distances of ten years ago are now sometimes accomplished by single kilowatt installations, such for example as when a ship in the Gulf off Florida sends its message direct to Denver!

While not seeking the robe of a prophet I will however venture the opinion that if trans-Atlantic telephony is ever accomplished it will be by means of the upper medium rather than by any sub-marine cable.

The one who works in "Wireless" must regard first of all the practical need of the art, must concentrate on every-day realities. He must deal with kilowatts and generators and earth-plates, foregoing the ever-present temptation to idle speculation. And yet many times in reverent mood he may look aloft into the sky at the spider traceries of his antennæ-wires, and wonder what and why they are, or by what mystery those simple lines have power to vibrate to the unseen waves, to send out even to the ends of the earth those strident yet all-inaudible messengers. And one may well marvel as he hears their voices in the tiny responder, some loudly distinct although from a thousand miles, and some as faint, as dim, as scarcely realized, as shadows on the wind.

Such are the marvels, such the promise, of this youngest science, which has grown so fast. In many lands far separate, by strange distant seas, these wireless masts now are planted, pinning down as it were into closer and more intimate contact the texture of the ether to the earth—uniting more and more the fabrics of the upper and the under worlds—interlinking *Thought* with *Reality*.

THE FRANKLIN INSTITUTE.

In Memoriam.

Samuel Sartain.

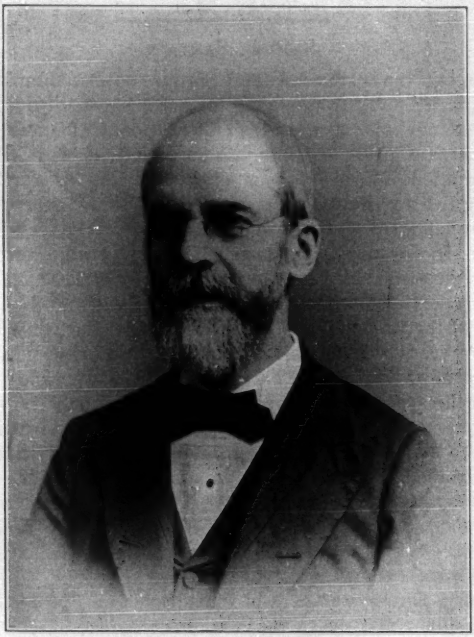
Through the death of Samuel Sartain, on December 20, 1906, there passed away from among the active spirits of the Franklin Institute one who, as a member of its Board of Managers during the past forty-one years, has surpassed all his colleagues in the duration of his continuous service and who had furthermore, during the last twenty-three years of that time, borne the added responsibility of duty as its Treasurer. In these directions alone, Mr. Sartain's labors in behalf of the Institute, and through it, for the community at large, have been of marked importance. But his services extended beyond the councils and the counting room of the Institute, into the fields of its distinctive work. He had for years been an assiduous member and, at one period, was Chairman of the Institute's Committee on Science and the Arts, in which capacity he took part in numerous of the scientific investigations undertaken by that committee. As chairman and reporter of various of the sub-committees charged with special investigations in the domain of the graphic arts, Mr. Sartain was the author of many valuable contributions to the literature of these subjects, which were published from time to time in the Journal of the Franklin Institute, and which, together, would make a considerable volume.

Samuel Sartain was born in Philadelphia on October 8, 1830. He was the eldest son of the celebrated engraver, John Sartain, who became famous as the earliest and leading exponent in America of that style of steel engraving known as the mezzotint.

The younger Sartain followed in the footsteps of his gifted father and eventually attained a degree of distinction in his profession which not only maintained, but also extended the fame of the Sartains as masters of their difficult and exacting art. He early envinced a marked talent for his work, studying both under the direction of his father and in the schools of the Pennsylvania Academy of the Fine Arts, and already in his seventeenth

year had so far mastered the technique of steel engraving as to successfully execute a three quarter length portrait of Benjamin West, after a painting by Harlow, on a 10x13 inch plate.

In 1854, he was commissioned by the Art Union of Philadelphia to engrave for their annual distribution a large plate, 18x23,



Samuel Sartain

reproducing a painting by C. Schuessele, a winter coasting scene, entitled "Clear the Track." This engraving won for him a silver medal at an exhibition of the Franklin Institute and an "honorable mention with special approbation" at the World's Fair in New York. This work was followed by other of his large pro-

ductions, prominent among these being the plates entitled "One of the Chosen," after Guy; "Christ Stilling the Tempest," after Hamilton; "The Song of the Angels," after Thomas Moran; "Christ Blessing Little Children," after Eastlake; "Evangeline," and more recently "The Pompeiian Water Carrier." In 1896 he executed a large and very notable portrait of the late Simon Muhr for the executors of that philanthropist's estate, and less than a year ago he finished a large portrait of the late President of the Pennsylvania Railroad, A. J. Cassatt, both of which are very fine examples of his work in the line of portraiture.

The publication of illustrated biographical encyclopædias for cities, countries and states, which has developed so largely during the past twenty-five years, brought to Mr. Sartain an endless demand for his productions. He was throughout this period the favorite artist of the biographical publishers, and having the rare faculty of catching and bringing out the characteristic expression and likeness of the original, even where the copy was more or less defective, his work easily retained its leading place against the inroads of the photo-reproductive processes.

Besides his constant participation in the proceedings of the Franklin Institute, Mr. Sartain collaborated actively in the work of various associations more directly connected with his artistic pursuit. He was Vice-President of the Photographic Society of Philadelphia; Treasurer for many years of the Artists' Fund Society and closely identified with the Fellowship of the Pennsylvania Academy of the Fine Arts. His long and useful life was illuminated by a benign and sympathetic nature and he bore with an exceeding modesty, the esteem and the honors which his conscientious and successful efforts had gained for him.

Louis E. Levy, *Chairman;*
Henry R. Heyl,
Washington Jones,
Wm. H. Wahl.

Sections.

Section of Chemistry and Physics.—Stated meeting held Thursday, April 25th, 8 P.M. Dr. Wahl in the chair. Present, twenty members and visitors.

The Chairman introduced the speaker of the evening, Mr. Fred. E. Ives, of New York, who presented a communication on "A New Color Meter."

The speaker illustrated his remarks by means of blackboard sketches and exhibited a specimen color meter built in accordance with his plans, with which he made some demonstrations.

On Dr. Partridge's motion, duly seconded, the subject of the invention was referred for investigation and report to the Committee on Science and the Arts.

Adjourned.

E. A. PARTRIDGE, *Sec'y.*

Regular meeting held Thursday, May 2d, 8 P.M. President Dr. Robert H. Bradbury in the chair. Present, forty-two members and visitors.

The speaker of the evening, Dr. W. H. Walker, of the Massachusetts Institute of Technology, was introduced by the Chairman, and gave a communication on "The Chemistry of Cellulose."

The speaker illustrated his remarks with the aid of lantern photographs and a large collection of samples of products made from derivatives of cellulose.

The subject was discussed by Dr. Ed. Goldsmith, Dr. Wm. J. Williams and others.

The President extended the thanks of the meeting to the speaker and adjourned the session.

E. A. PARTRIDGE, *Sec'y.*

ELECTRICAL SECTION.—Stated meeting held Thursday, May 16th, 8 P.M. President Thomas Spencer in the chair. Present, fifty-six members and visitors.

The paper of the evening was read by Mr. C. O. Mailloux, of New York, on "The Electrification of Steam Railroads." The subject was profusely illustrated by means of lantern photographs.

After some discussion of the subject, the thanks of the meeting were voted to the speaker and the session was adjourned.

WM. H. WAHL, *Sec'y pro tem.*

The Franklin Institute.

(Proceedings of the stated meeting held Wednesday, May 15, 1907.)

PRESIDENT WALTON CLARK in the chair.

Present, twenty-one members.

Additions to membership since last report, six.

The first communication of the evening was presented by Mr. J. C. Trautwine, Jr., on Street Obstructions in Philadelphia, under the title of "A Libel on Philadelphia Refuted," illustrated by lantern photographs showing several of the city's prominent business streets, nearly two-thirds

of the width of which was occupied by builders' materials. The communication was freely discussed by the President, Prof. Lewis M. Haupt, Joseph W. Richards, Drs. Edward Goldsmith, W. J. Williams and Messrs. Louis E. Levy, Warner Walter, H. F. Colvin and the author.

Prof. Joseph W. Richards, of Lehigh University, by invitation, followed with an informal address, describing a number of the most notable of "Recent Advances in Electrometallurgy." In his remarks the speaker referred particularly to the following subjects—Electrolytic Sodium, Calcium, the De-tinning of Tinplate, the Electrolytic Refining of Gold and Silver, Electrolytic Lead Refining, Copper Refining, the Growth of the Aluminum Industry, Electric Iron and Steel Production, and the Electric Production of Zinc.

The communications of the evening were referred for publication and the authors received a vote of thanks.

The President called the attention of the meeting to an invitation received from the Michigan Agricultural College to participate in the commemoration of the 50th anniversary of the Institution. The Secretary was instructed to prepare and transmit a suitable acknowledgement of the invitation, expressing the felicitations and good wishes of the Franklin Institute.

Adjourned.

WM. H. WAHL, *Secretary.*

Committee on Science and the Arts.

(Abstract of proceedings of stated meetings held Wednesday, March 6th, 1907.)

DR. W. O. GRIGGS in the chair.

The following reports were adopted:

(No. 2389.) *Improved Thermometer Support.* T. F. Townsend, Philada.

(Report on this subject passed second reading and was adopted after amendment. As notice has been received that the case will be reopened, the abstract will be deferred until it has been finally disposed of.)

(No. 2399.) *Device for Relieving Forces Due to Inertia and Weight of Valve Gears.* Luther D. Lovekin, Philadelphia, Pa.

ABSTRACT:—The invention of Mr. Lovekin is secured by Letters Patent of the United States No 775,573, dated Nov. 22, 1904, and is fully described in a paper published in transactions of the American Society of Naval Engineers, Vols XVI and XVII, No. 3, and also in a paper read before the same society by Ensign W. W. Smith, U. S. N., (August, 1906).

While Mr. Lovekin's design is not restricted in its application to a particular form of valve, it is particularly adapted to the ponderous piston valves, most frequently applied to marine engines. It consists of an external cylinder, concentric with the cylinders of the piston valve, and a balancing piston in said external cylinder, attached to a prolongation of the main valve stem, and so proportioned and ported as to practically balance

or neutralize the force acting on the reciprocating parts, due both to the weight and the inertia of these moving parts.

Mr. Lovekin preferably attached this balancing cylinder to the receiver of the compound engine, as the variable receiver pressure is found to best suit the conditions of varying velocity in the valve.

On large vertical engines, such as used in marine service, the weight of the reciprocating parts of the valve gear amount to several thousand pounds, and as high velocities are now usual, it can be readily known that a well devised balancing device is very desirable. The use of a balancing piston to neutralize the weight of the valve is an old and well known device. The use of the steam cushion to absorb the inertia of the valve has also been used. It was applied to the larger size of the Westinghouse engine many years ago, and is fully described in patent specifications No. 342,307 by F. M. Rites, under date of March 17, 1886.

A somewhat similar device has been used by Joy, in England, but as this exhausts or wastes steam in its action, it cannot be classed with the designs of Rites and Lovekin, neither of which exhaust steam in their operation. The design of Rites involves an enlargement of the diameter of the main piston valve, and a direct cushioning of the same in its cylinder, while the design of Lovekin, acting through a piston external to the main valve, and so designed that the location or arrangement of the regulating parts can be readily modified to suit the conditions of the service, offers a means of accomplishing the desired purpose in a very satisfactory manner. These balancing or assisting cylinders have been applied to several engines, both of the U. S. Navy and of the Commercial Marine, and are reported as having proved efficacious.

The report in conclusion recommends the award to the inventor of the John Scott Legacy Premium and Medal. *(Sub-Committee:*—James Christie, Chairman; T. Carpenter Smith and William H. Thorne.)

(No. 2393.) *Speed Indicator.* Hermann Frahm, of Hamburg, Germany.

Abstract:—In 1902, Mr. Hermann Frahm, chief engineer of a shipyard of Hamburg investigated the effect of torsional vibrations in propeller shafts, and found that the disastrous results were due to the well known property that elastic bodies possess of being set in vibration if they are subjected to rhythmic impulses, the frequency of which corresponds with the natural period of vibration of the bodies themselves. This is the principle of resonance. When he had found a means of suppressing the dangers arising from this cause, it occurred to him to devise a method of utilizing this same principle for the purpose of counting vibrations and measuring speeds. This speed indicator is the result.

An element of the indicator consists of a straight flat piece of watch-spring steel 3 mm. wide and 0.25 mm. thick. About 4 mm. of its upper end is bent over at a right angle, and in the angle is placed a small drop of solder, while the head is covered with white enamel to make it readily visible. A series of these springs of graduated lengths, varying ordinarily from 40 to 55 mm., are pinned and soldered in a slit cut in a rectangular bed. By properly arranging the lengths and altering the amount of solder at the head, any desired period of vibration between 35 and 100 per

second can be obtained. By the use of long and thin, or short and thick springs, the range of vibration can be further extended if desired. An assemblage or comb of such springs, attuned to graduated periods, is screwed to a rod 6.5 mm. square with 1 mm. space between each spring, and is held in a case so that the enameled ends are flush with a dial having a rectangular opening, wide enough to permit the vibrations, and with a scale to show the number of these vibrations. The length of the comb and the difference between the period of vibration of the adjacent springs can be varied to suit the requirements of any particular case, but this difference is usually made 2 per cent. The method of setting the comb in vibration depends on the number of revolutions of the machine to be counted. If these exceed a thousand per minute, the comb can be attached directly to the frame of the machine. If less than this, a cam with two or more tubes can be placed on the shaft and arranged to vibrate the comb.

If it is desired to indicate the speed of a machine at a great distance from it, this can be done by electrical transmission. A simple alternating current generator is driven by the machine and the current carried to a magnet placed on the bridge of the comb, which is thus made to vibrate in correspondence with the frequency of the current. All the springs are thus made to quiver slightly at their lower ends, and that particular spring whose natural period of vibration is most nearly in unison with the actuating impulses will be thrown into very strong vibration, and when these vibrations are exactly in synchronism with the natural period of a spring the amplitude will reach its maximum.

For indicating the speed of electrical machines, this invention is excellent. It can be used for paralleling alternators and polyphase generators, as a phase indicator, and for the determination of the slip of an induction motor. It also permits of the observation and supervision at one place of the running of any number of machines, and gives a centralization of management in a very efficient way.

The report concludes with the recommendation to the inventor of the John Scott Legacy Premium and Medal. *(Sub-Committee:*—William H. Thorne, Chairman; Jacob Y. McConnell and Richard L. Binder.)

The following report passed first reading:—

(No. 2405.) *The Contributions of the Baldwin Locomotive Works, of Philadelphia, Pa., to the Evolution of the American Locomotive.*

NEW BUSINESS.

(No. 2382.) *Etch-Powdering Machine.* Louis E. Levy, Philadelphia, Pa.

Under reconsideration proceedings the report on this case was amended by unanimous vote by substituting for the John Scott Legacy Premium and Medal the award of the Elliott Cresson Medal.

LOUIS E. LEVY, *Sec'y pro tem.*

(Stated meeting held April 3, 1907.)

DR. W. O. GRIGGS in the chair.

(No. 2405.) *The Contributions of the Baldwin Locomotive Works, of Philadelphia, Pa., to the Evolution of the American Locomotive.*

The report is reserved for publication in full.

The following report passed first reading:

(No. 2387.) *Complete Expansion Gas Engine.* C. E. Sargent, of Chicago, Ill.

LOUIS E. LEVY, *Sec'y pro tem.*

(*Abstract of proceedings of the stated meeting held Wednesday, May 1, 1907.*)

DR. WM. O. GRIGGS in the chair.

The undermentioned reports were adopted:—

(No. 2363.) *Insulated Fireproof Wire.* J. Allen Heany, of York, Pa.

ABSTRACT:—This invention is protected by numerous Letters Patent granted to applicant and issued between dates of June 24, 1902, and March 15, 1904. These patents cover the machinery for applying the fireproof coating to the wire and the product. Prior to Mr. Heany's invention it has been shown to the satisfaction of the Committee that the only method of applying asbestos to a wire or other electrical conductor, consisted in spinning asbestos into a thread and then winding this thread spirally around the wire. The Committee refers in its report to several inventions of this character, viz:—that of Shuster (March, 1879,) and Splitdorf (June, 1888), and in commenting thereon, state in their report that this insulation has the serious disadvantage of opening and forming interstices between the windings of the thread when the wire is bent, which in turn causes short circuiting and thus, destruction of the wire in coils or armature windings, and leakage and danger to wood work and other inflammable material in buildings. The report notes other defects of this method of applying the insulation, but those above are the most conspicuous.

The Committee takes notice of a patent to Downes (February, 1895,) in which the inventor sought to overcome the defects of this insulation by raising a portion of the spiral thread of asbestos into a nap and then compressing the nap into the interstices; but this does not accomplish the desired purpose satisfactorily.

Mr. Heany departs from the path of his predecessors in abandoning the use of an asbestos thread and makes use of raw, flocculent asbestos, which has only been freed from impurities. By suitable mechanism Heany separates his asbestos into a filmy state and in this condition feeds it to the wire and forms thereon a thin homogeneous layer. Each fibre of the asbestos in this layer is spirally wound upon the wire or conductor and by an adhesive coating is firmly connected therewith. By this method the coating will not show interstices when the wire is sharply bent or twisted. The wire is subsequently treated with a waterproof composition, which forms a thin, pliable, enamel-like coating on the surface of the asbestos and renders it impervious to moisture.

Mr. Heany's method permits him to use the waste asbestos and asbestos of the lowest grade, being in strong contrast to the earlier methods of spinning a thread which required the use of the best material and longest fiber. This substantially reduces the cost of the material employed.

The report submits in the form of appended documents, a mass of evi-

dence in substantiation of the claims of the inventor, and finally concludes in the following terms that "Mr. Heany has done something which heretofore could not be accomplished manually or mechanically, and in view of the importance of the invention to the electrical industries, is entitled to the highest award of the Institute—the Elliott Cresson Medal." (*Sub-Committee*, Washington Deveraux, Chairman; Wm. McDevitt, Wilhelm Vogt and L. F. Rondinella.)

(No. 2387.) *Complete Expansion Gas Engine.* C. E. Sargent, of Chicago, Illinois.

ABSTRACT:—The above invention is covered by a series of U. S. Letters Patent granted to applicant between Feb., 1900, and Feb., 1905. Copies of papers fully describing the invention in detail are submitted in the application. Blueprints showing efficiency tests are also filed with the papers.

The main feature in this engine lies in the method used for expanding the products of combustion to nearly atmospheric pressure. The cycle used is a modification of the Beau de Rochas or Otto Cycle. The admission of the explosive mixture is cut off at any desired point of the stroke, and thereby the compression is somewhat varied and the expansion considerably increased. The cut-off is controlled by a governor, thus being used to regulate the speed of the engine.

The desirability of a more complete expansion of the products of combustion has long been recognized, and various machines have been built to accomplish this purpose, such as Atkinson's cycle engine in England, the Niel, Charon and other engines in France. These, however, accomplished the results by means entirely different than those used by Sargent. The cycle he adopts is nevertheless not new, having been proposed by Koehler in 1895, and later practically applied by Koerting.

The governor, which is of the Rite's inertia type, controls all cams, advancing them more or less with reference to the crank. When the speed goes beyond normal, the cut-off, exhaust and exhaust closure as well as ignition are advanced. By this means some of the burned gases are imprisoned, thus causing a slight compression at the end of the scavenging stroke. The compression delays the admission, as the inlet poppet valve acts automatically by the suction produced by the piston as soon as the pressure within the cylinder drops below air pressure. Thus with light loads the admission is less from two causes, 1st, by the later admission; and 2nd, by the earlier cut-off. The imprisoned burned gases cause a more dilute mixture of the fresh charge and a higher compression. The ignition occurring earlier allows a longer time for the combustion of the poorer mixture and insures a high pressure at the early part of the power stroke.

Although the hit and miss principle of governing gas engines gives good economical results, it gives poor speed regulation. The form of governing adopted by Sargent gives a close speed regulation, and at the same time permits a great range of load variation and cut-off without appreciable loss in efficiency.

The greater expansion of the products of combustion reduces the ex-

haust temperature from the usual 1000° F. or more to the neighborhood of 400° F., making the average temperature existing in the cylinder much lower than in the gas engines of the usual type. This enables Mr. Sargent to construct his machine in the form of a double-acting tandem engine, and to obtain an impulse at each stroke of the engine.

The arrangement of the combined inlet and exhaust valve is somewhat on the order of that built by Fielding and Platt, and differs from it mainly in making exhaust valve a piston valve. This piston valve is ingeniously arranged so that it also acts as a cut-off valve, and furthermore, by being revolved can vary the mixture to suit the gas. By means of an ingeniously arranged dash-pot, the poppet valve is forced open, giving free admission to the charge.

Another simple and ingenious arrangement is the use of the spiral gears which drive the cam shaft, or an oil pump serving to distribute oil to all bearings.

It is the opinion of the Committee, that in the development of this engine a great deal of thoroughly scientific thought has been expended, and considerable ingenuity demonstrated by the inventor. He has produced an engine which in its nature should give high economy and close regulation, and has contributed to the advancement in the art of building internal combustion engines. The Committee therefore recommends the award of the John Scott Legacy Premium and Medal. (*Sub-Committee*, Arthur Falkenan, Chairman; Kern Dodge, Chas. Day and Chas. E. Ronaldson.)

(No. 2406.) *Machine for the Transmission of Power and Device for Hoisting Purposes.* Fred. G. Harbord, of Philadelphia, Pa.

This report was made advisory and adopted.

NEW BUSINESS.

A motion, duly seconded, was made to reconsider the Committee's action on Townsend's Thermometer Support. Under the rules, this was laid over for one month, or, until the next stated meeting.

WM. H. WAHL, *Secretary.*